



# **Linking Water Cycle to Carbon Cycle Over Ocean**

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Jet Propulsion Laboratory**

- **CO<sub>2</sub> partial pressure**
- **Acidification**

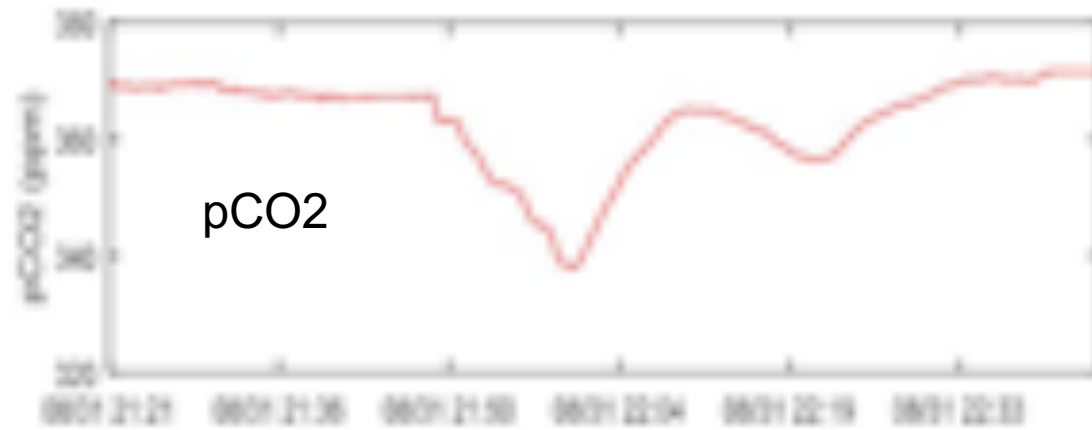
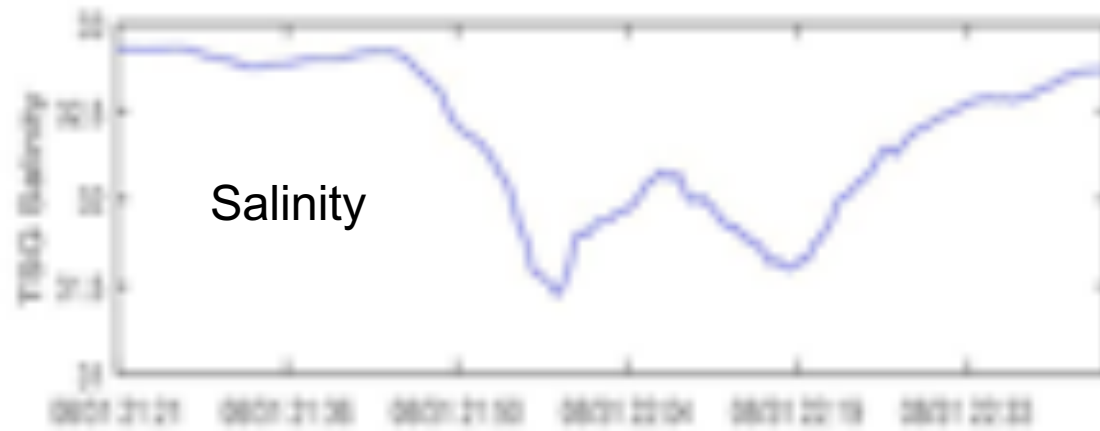
Linkage of water and carbon cycles in the atmosphere is obvious in the interaction of the two greenhouse gases with atmosphere adiation balance.

• Ocean absorbs about 25% of CO<sub>2</sub> we emit into the atmosphere and thus mitigate greenhouse warming. The CO<sub>2</sub> absorbed by the ocean increases ocean acidification that is harmful to marine life.

CO<sub>2</sub> flux has been parameterized to a piston velocity and  $\Delta p\text{CO}_2$ .  $p\text{CO}_2$  is critical in evaluating the flux, both for climate change and for spatial-temporal variation of ocean biogeochemistry.

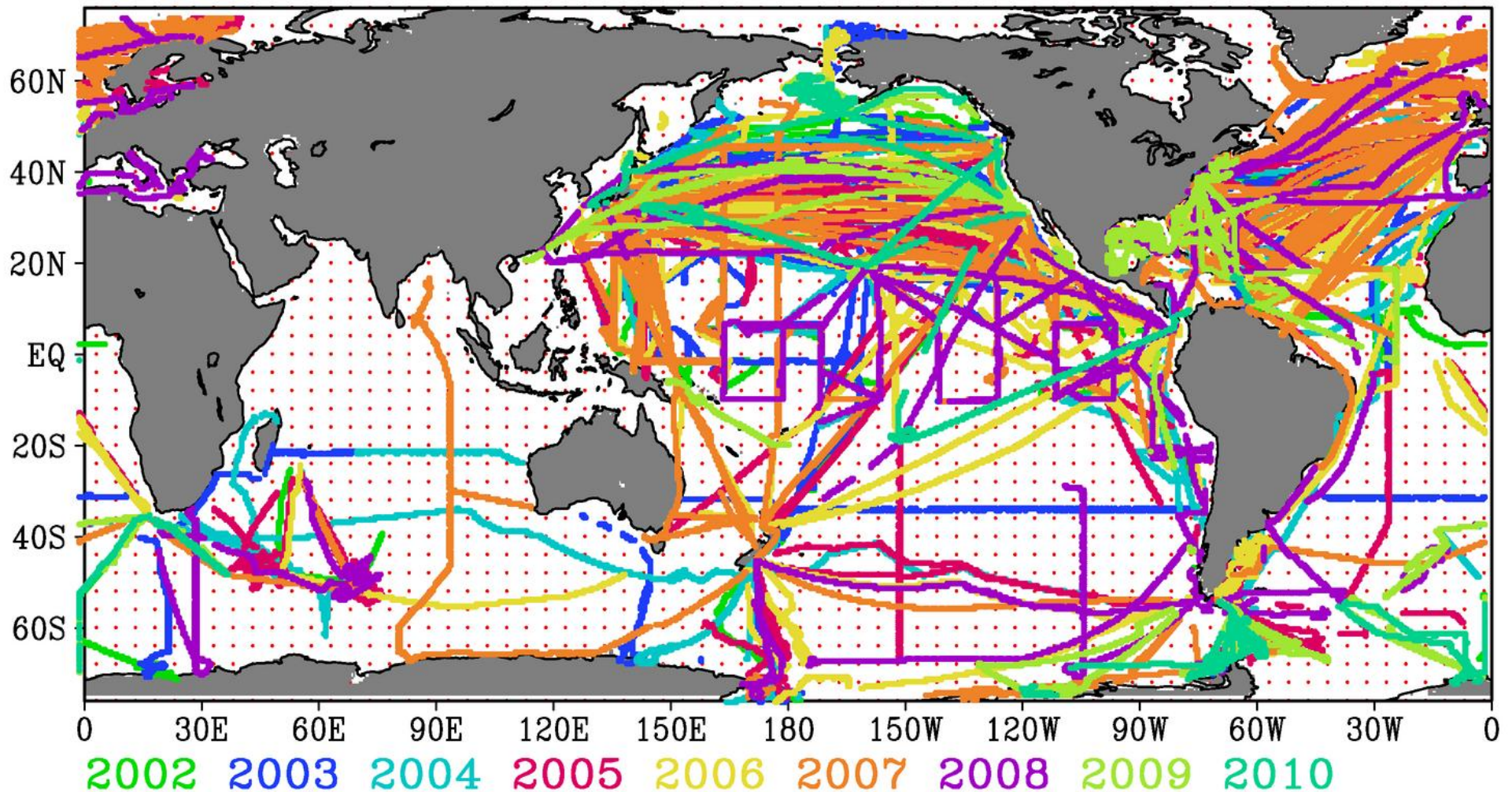
Ocean carbon system and acidification are usually described by 4 parameters,  $p\text{CO}_2$ , TA, dissolved inorganic carbon, and pH. Knowing two can resolve all through chemical equations.

30 minutes of  
rain episode in  
SPURS-2  
(courtesy of  
Julian Schanze  
and Eric Chan).



- **pCO<sub>2</sub> and acidification have been estimated through surrogates (drivers)**
- **Sea surface temperature (SST) governs thermodynamics and solubility**
- **Biological productivity is represented by chlorophyll. Photosynthesis and respiration deplete and add carbon.**
- **Water inputs (rain and river), in term of salinity, affect alkalinity and pCO<sub>2</sub>**
- **Correlation between pCO<sub>2</sub> and drivers could turn from positive and negative at various regions and seasons**

**We have collected 206,265 daily data points  
collocated with space data in 2012**



**Compiled from many sources through CDIAC**

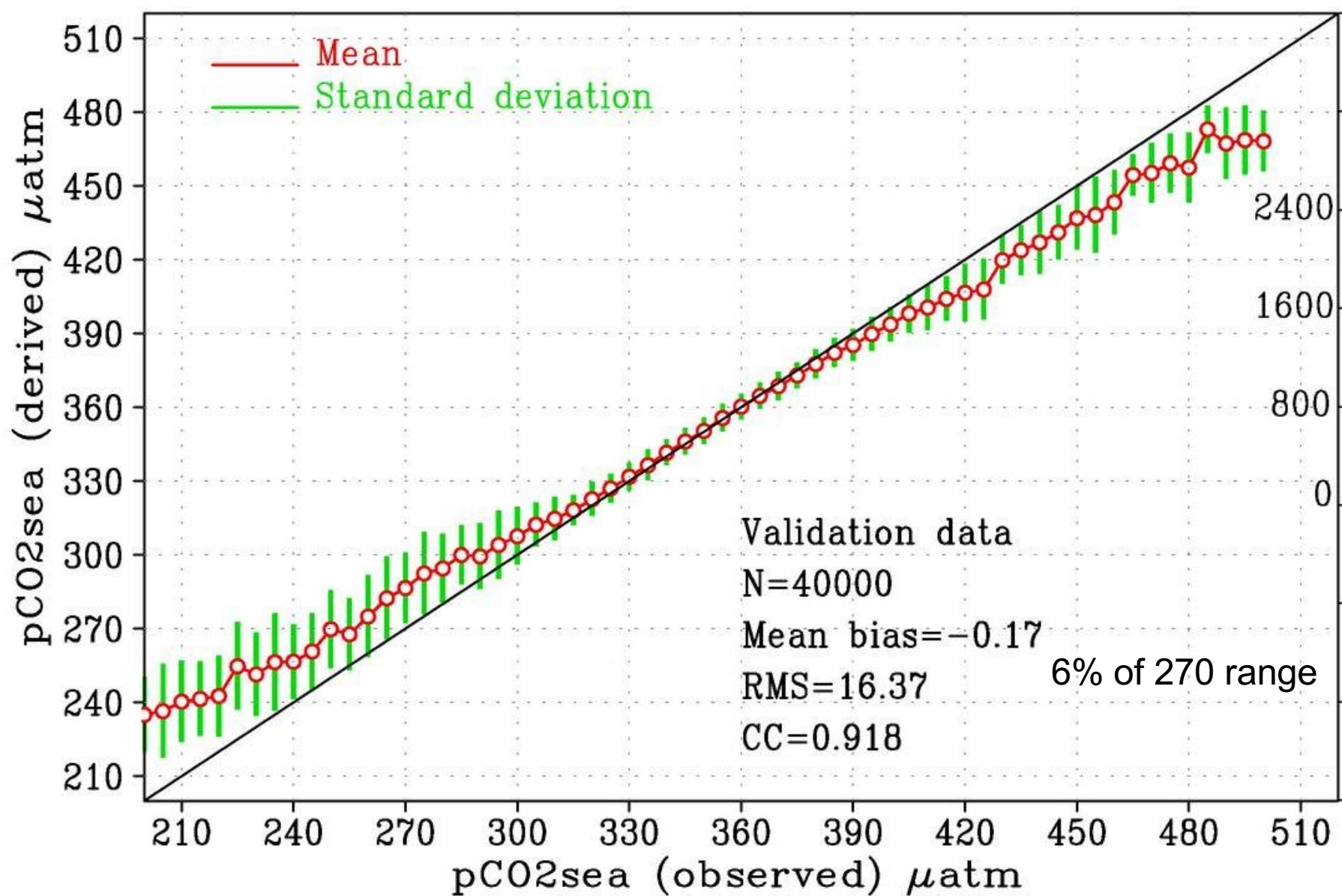
**□ Statistical model  $p\text{CO}_{2\text{sea}}$  and TA developed using support vector regression (SVR)**

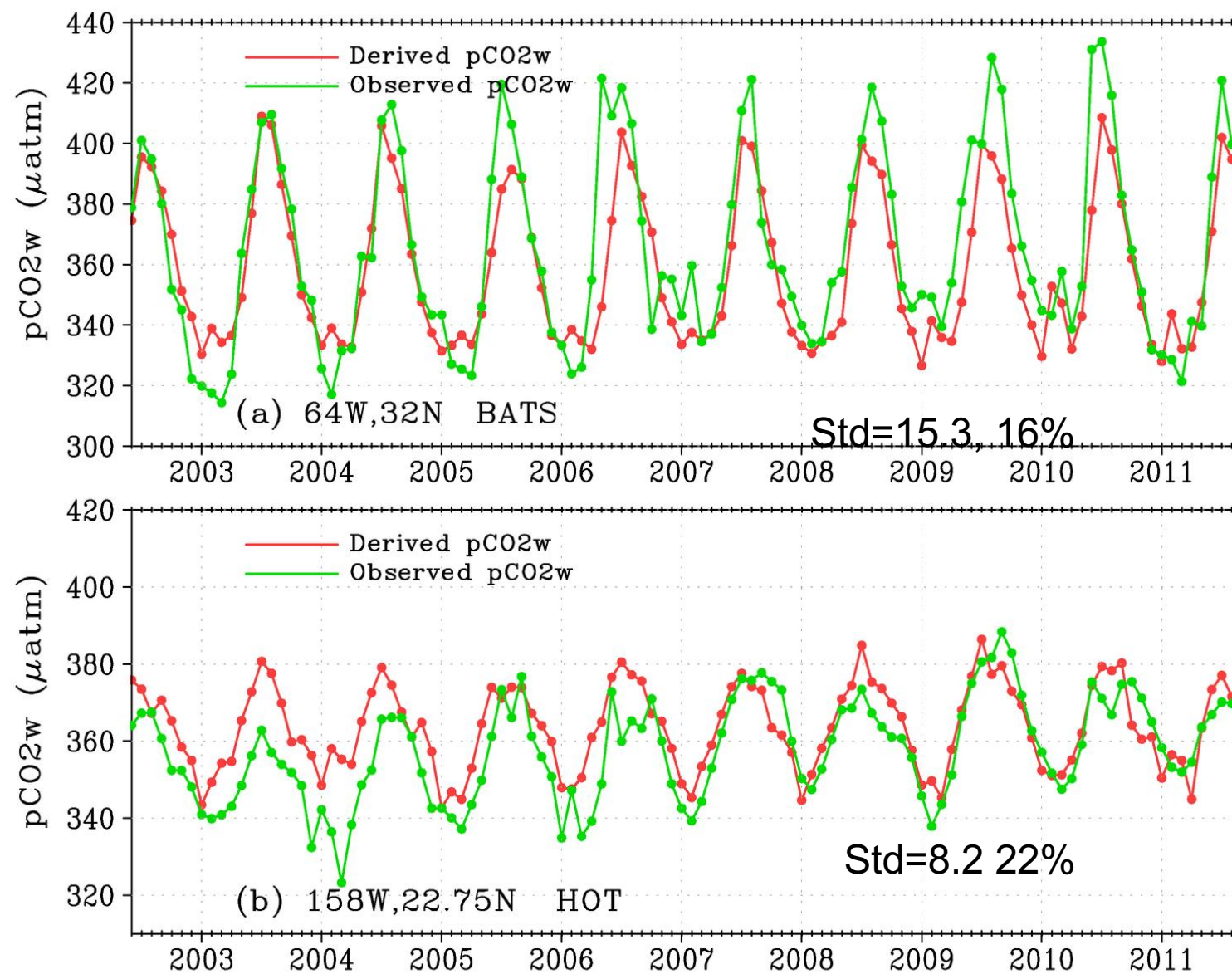
**□ Input:  $\sin(\text{day})$ ,  $\cos(\text{day})$ , lat,  $\sin(\text{lon})$ ,  $\cos(\text{lon})$ , SST (AMSR-E), Chl-a (SeaWiFS+MODIS), SSS (Levitus climatology)**

**□ 206265 data groups found 2002-2010  
40,000 randomly selected for training and  
40,000 for validation**

**□ Output: 9 year at  $0.5^\circ$ , 3-day resolution**

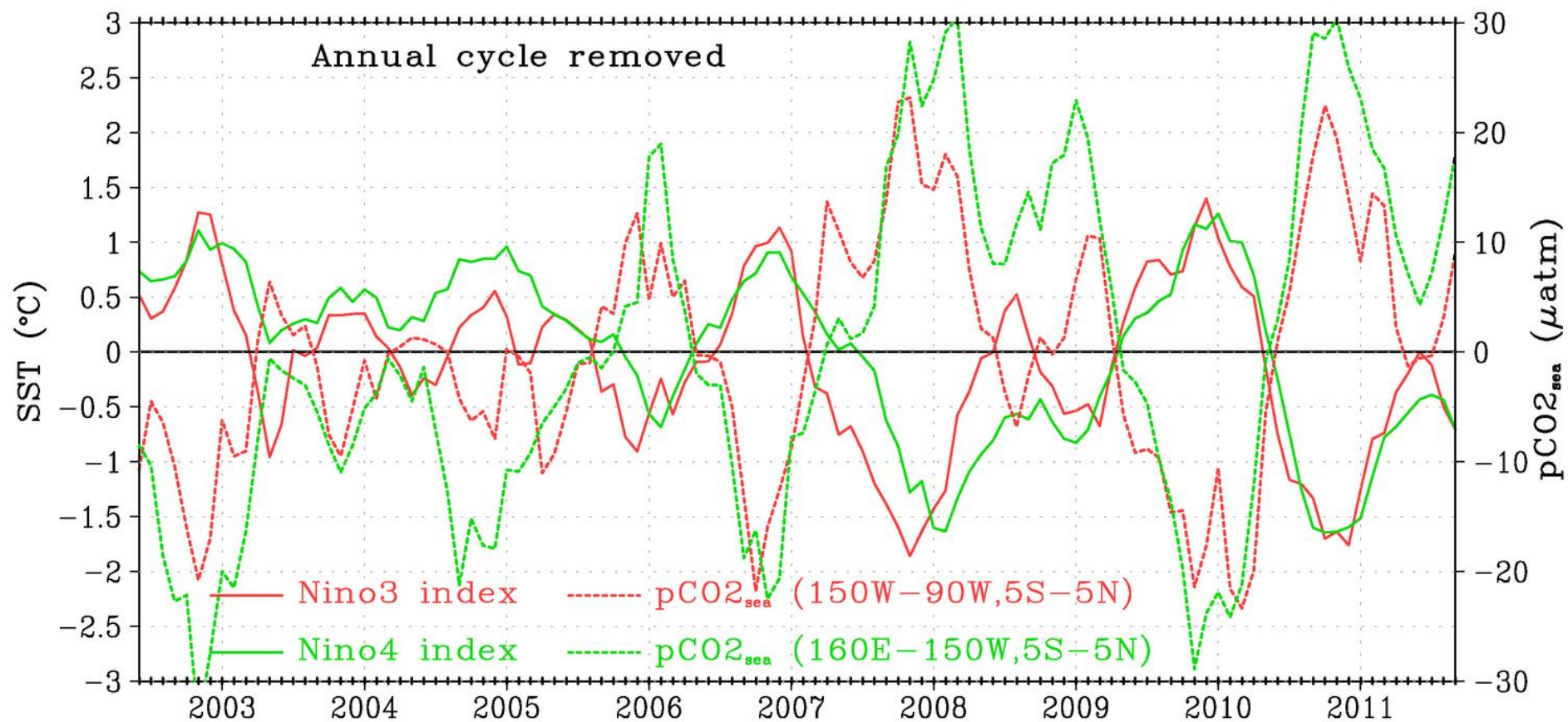
**□ <https://airsea.jpl.nasa.gov/DATA/seaflux/pco2/>**

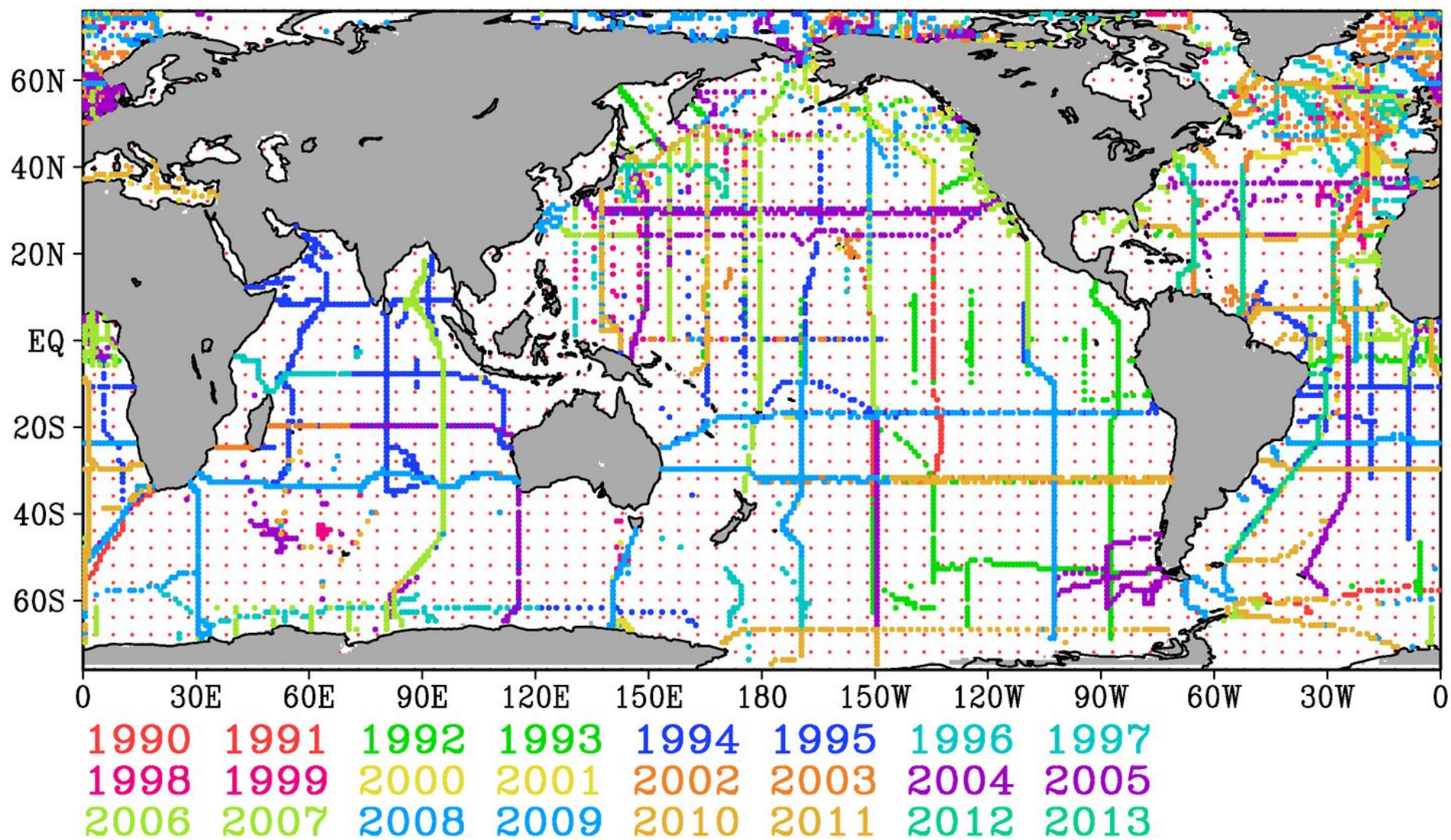


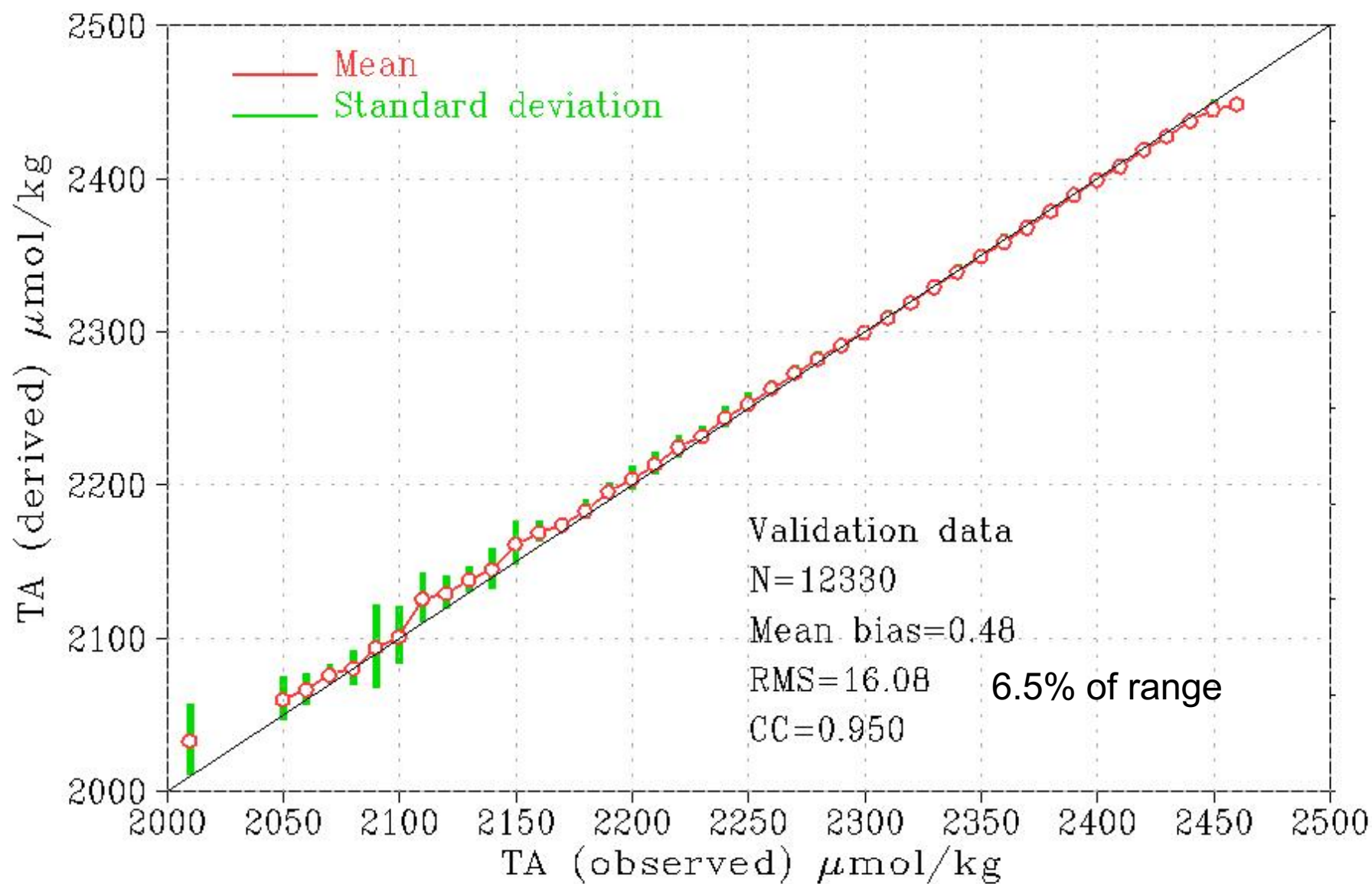


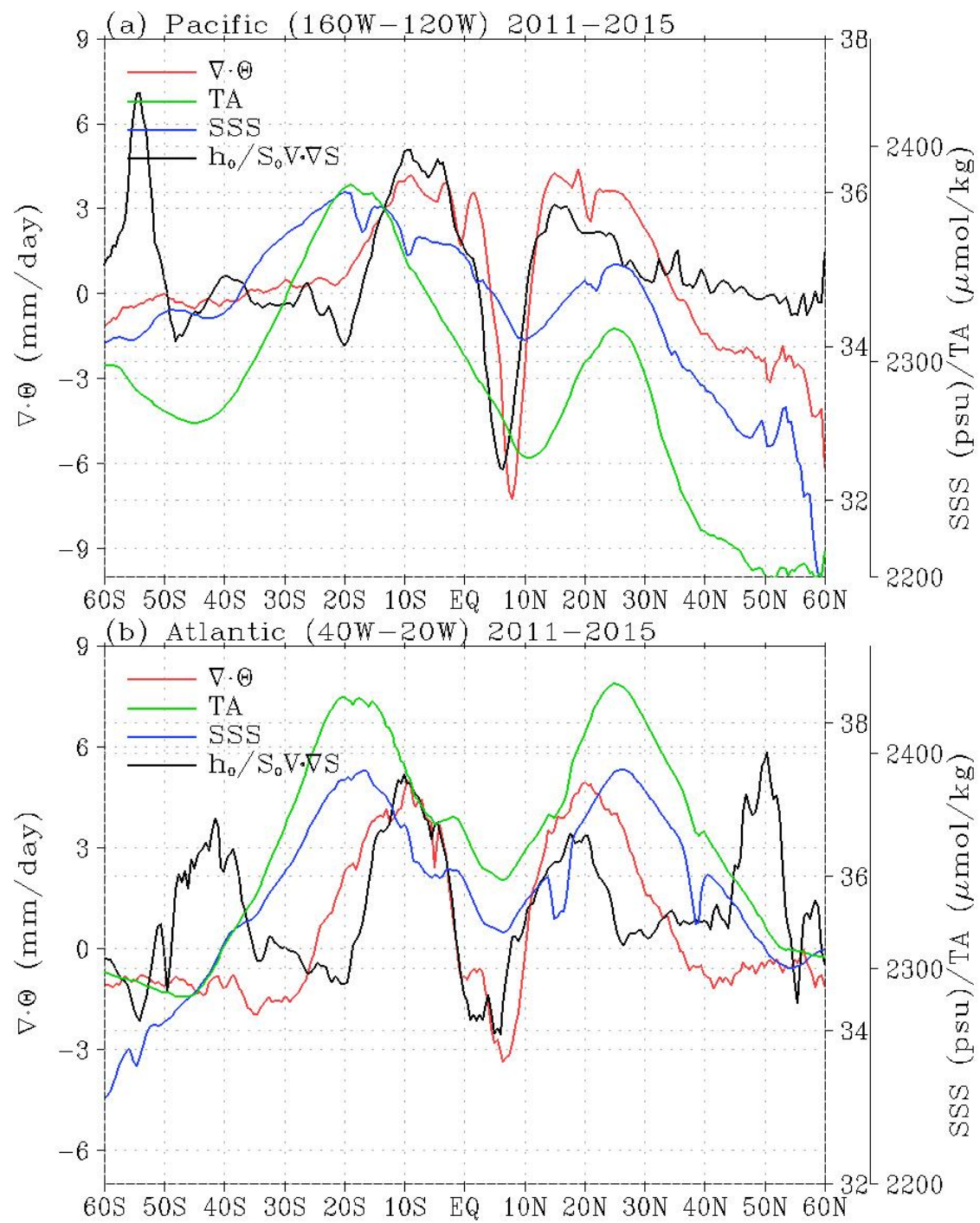
Model pick up magnitude and phase of annual cycle, lower range less long trend

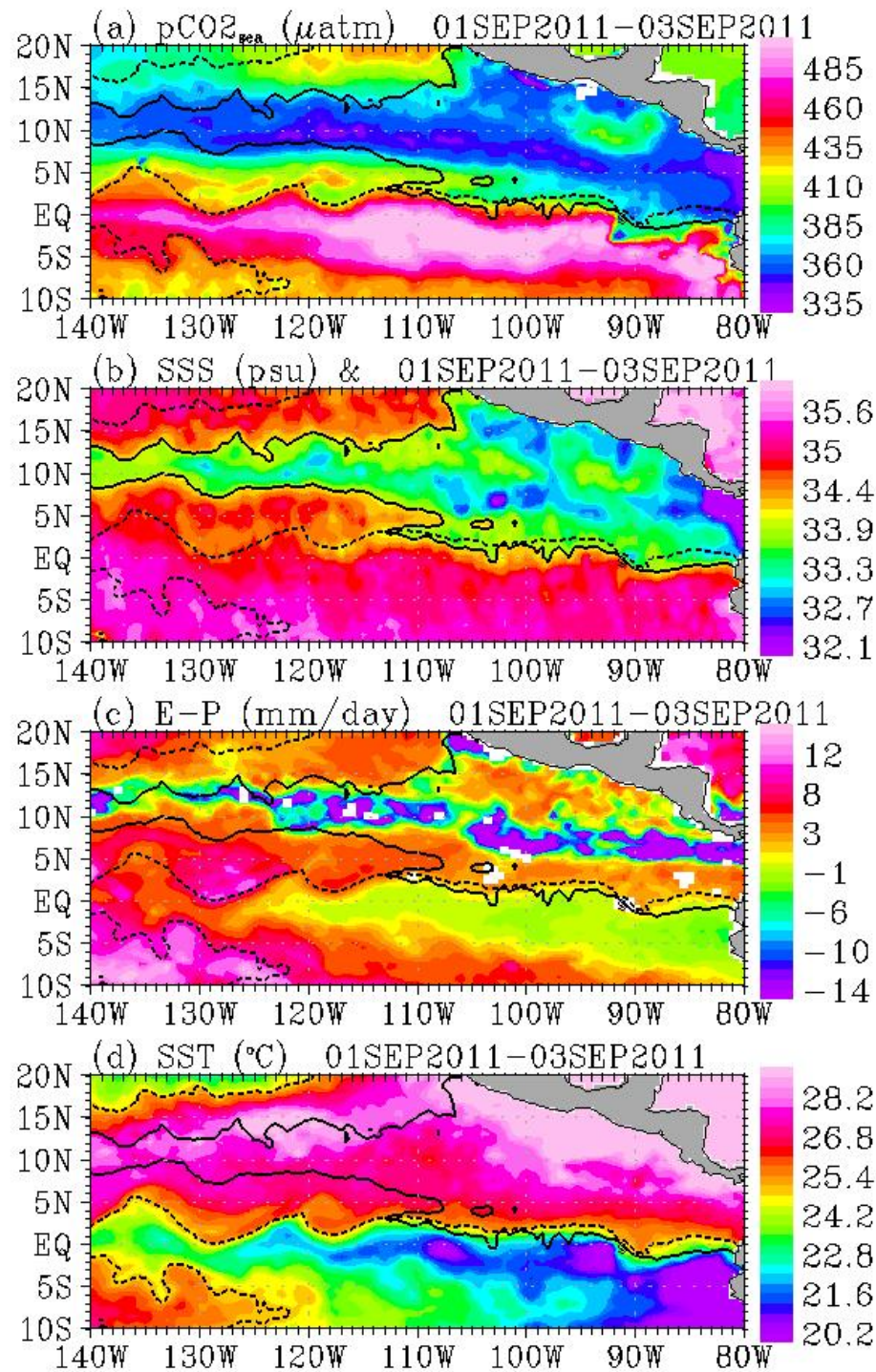
**Enhanced  $p\text{CO}_{2\text{sea}}$  during La Nino and suppressed  $p\text{CO}_{2\text{sea}}$  during El Nino**

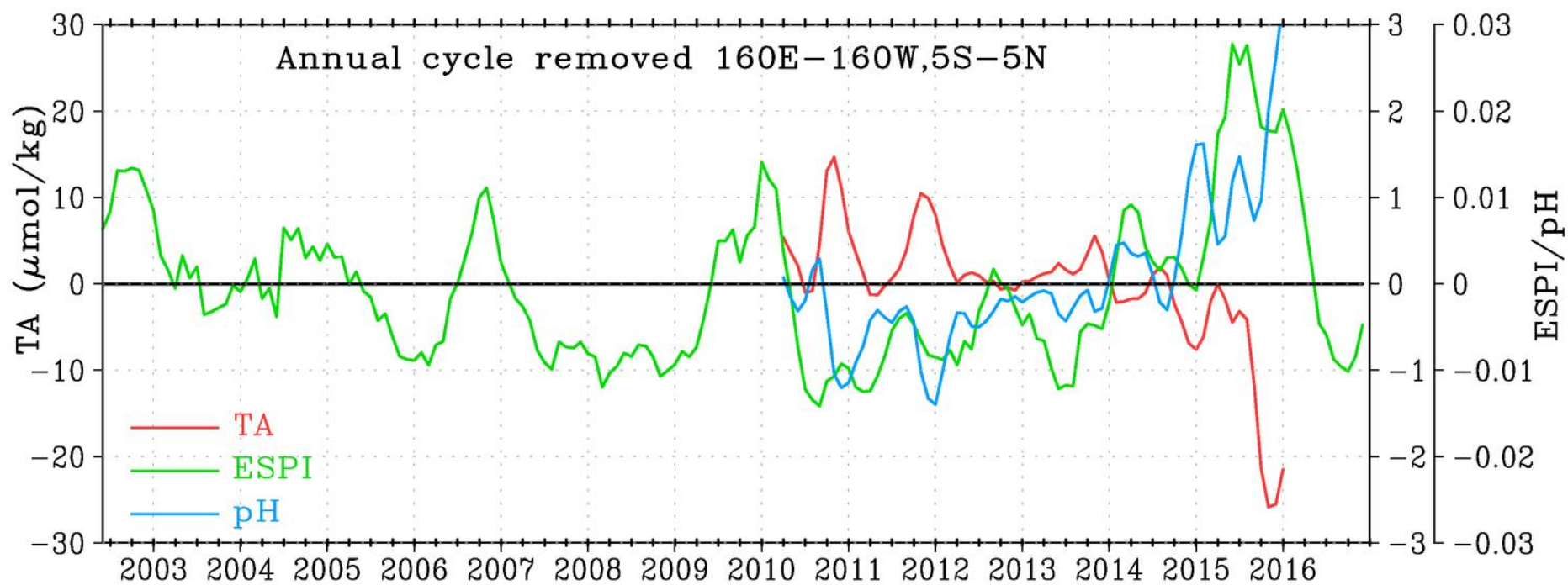
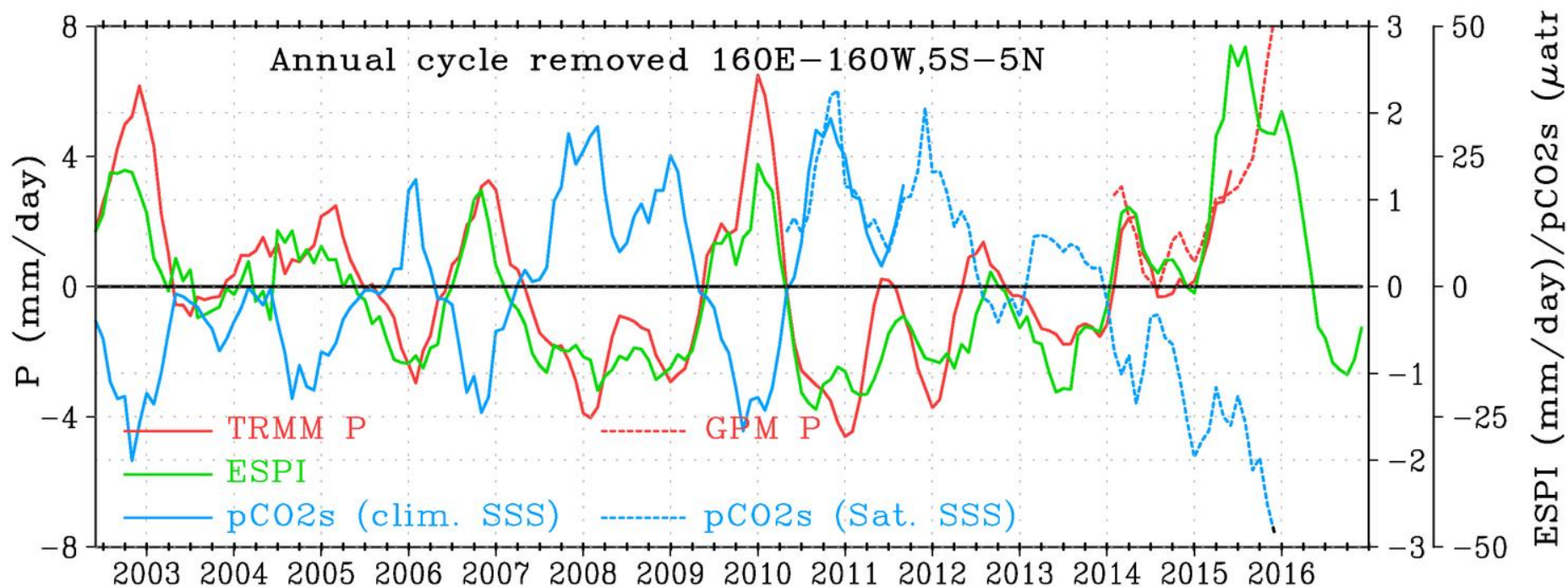




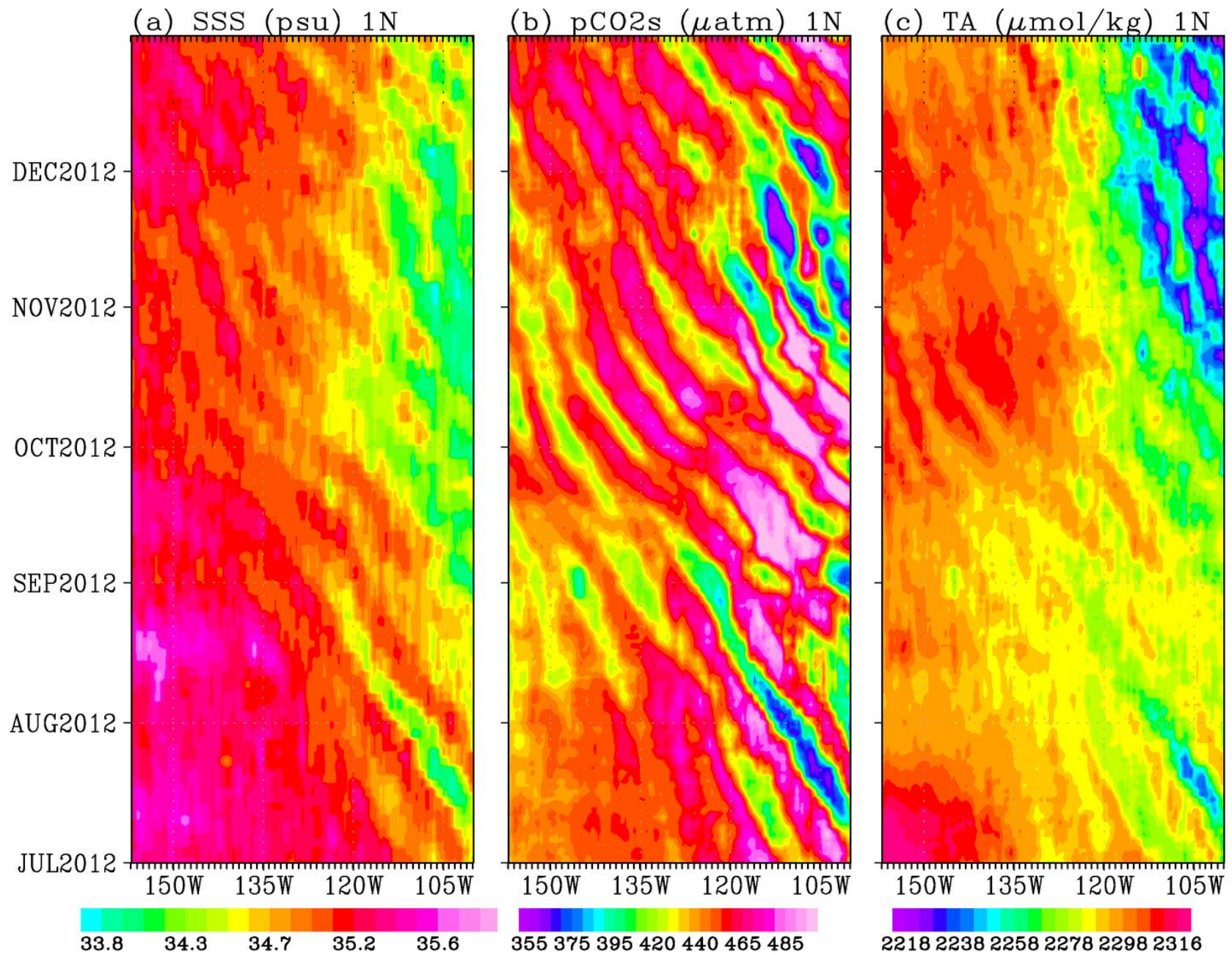


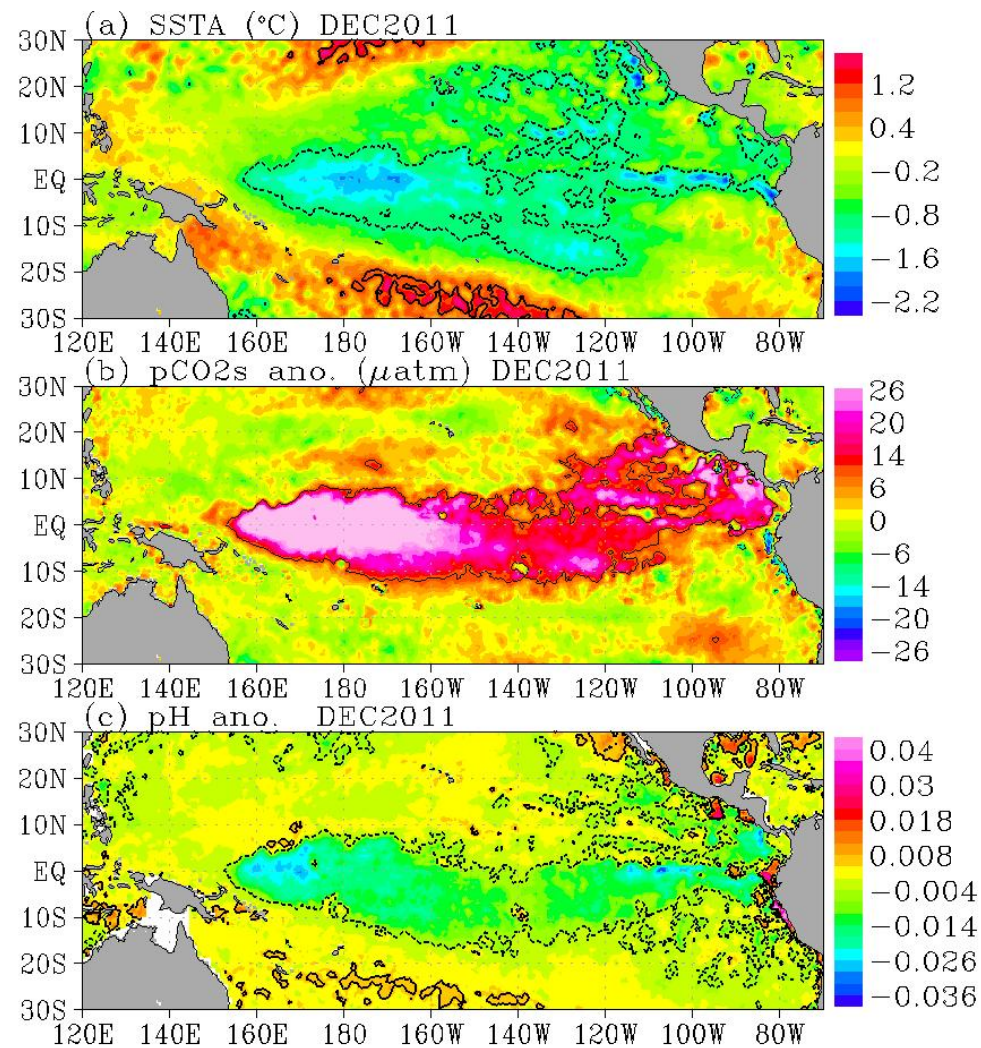
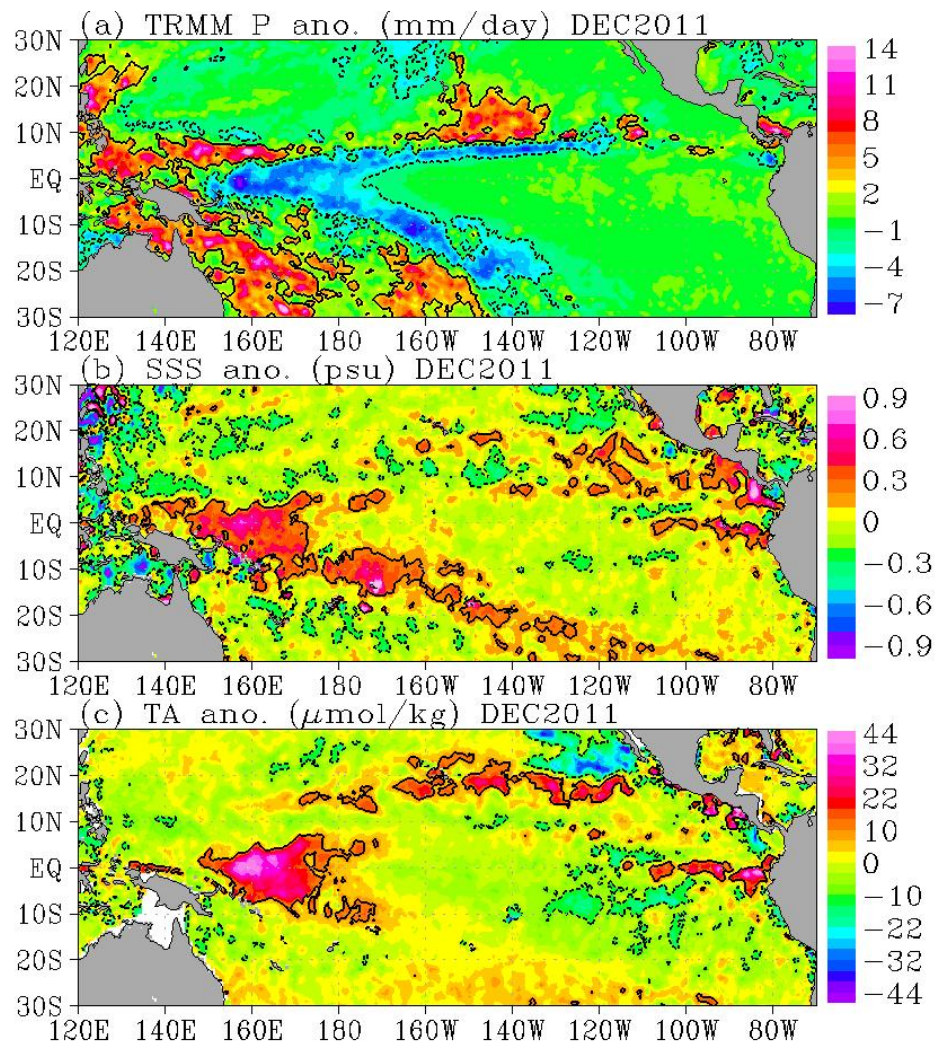




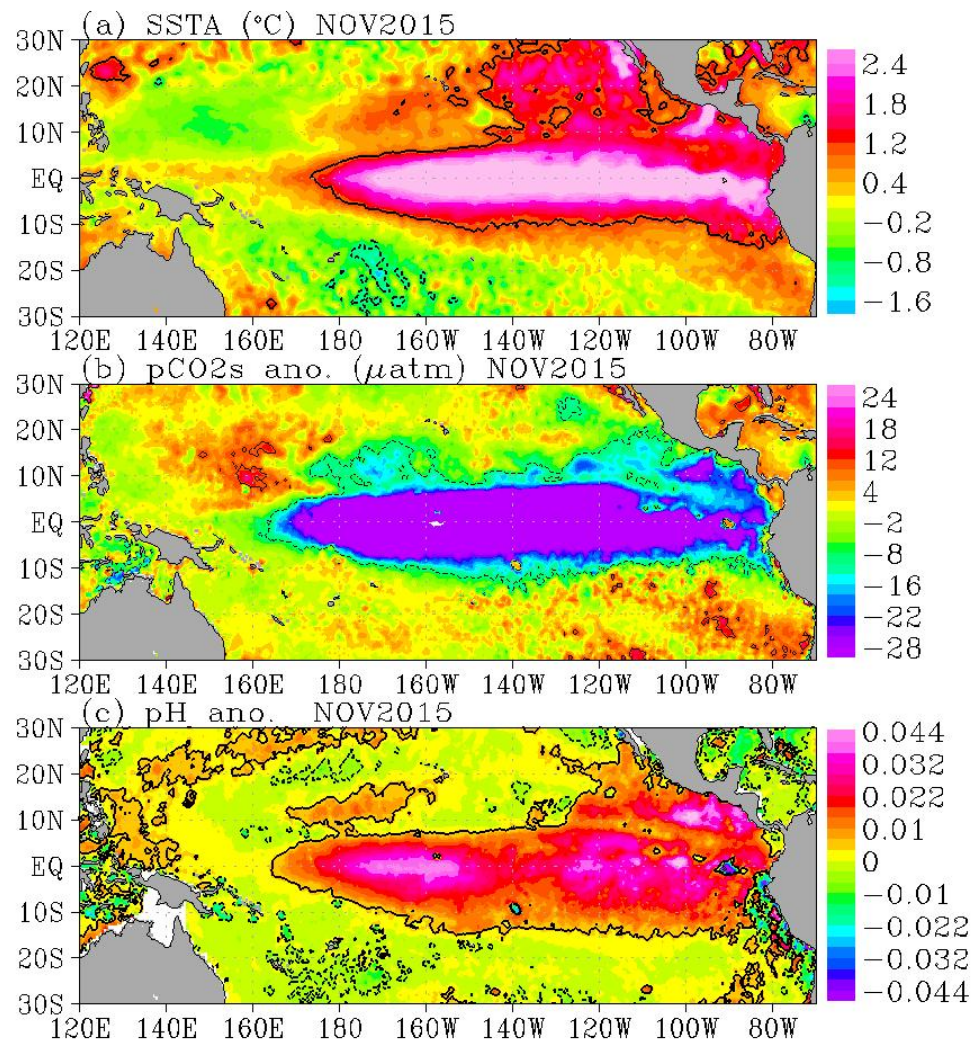
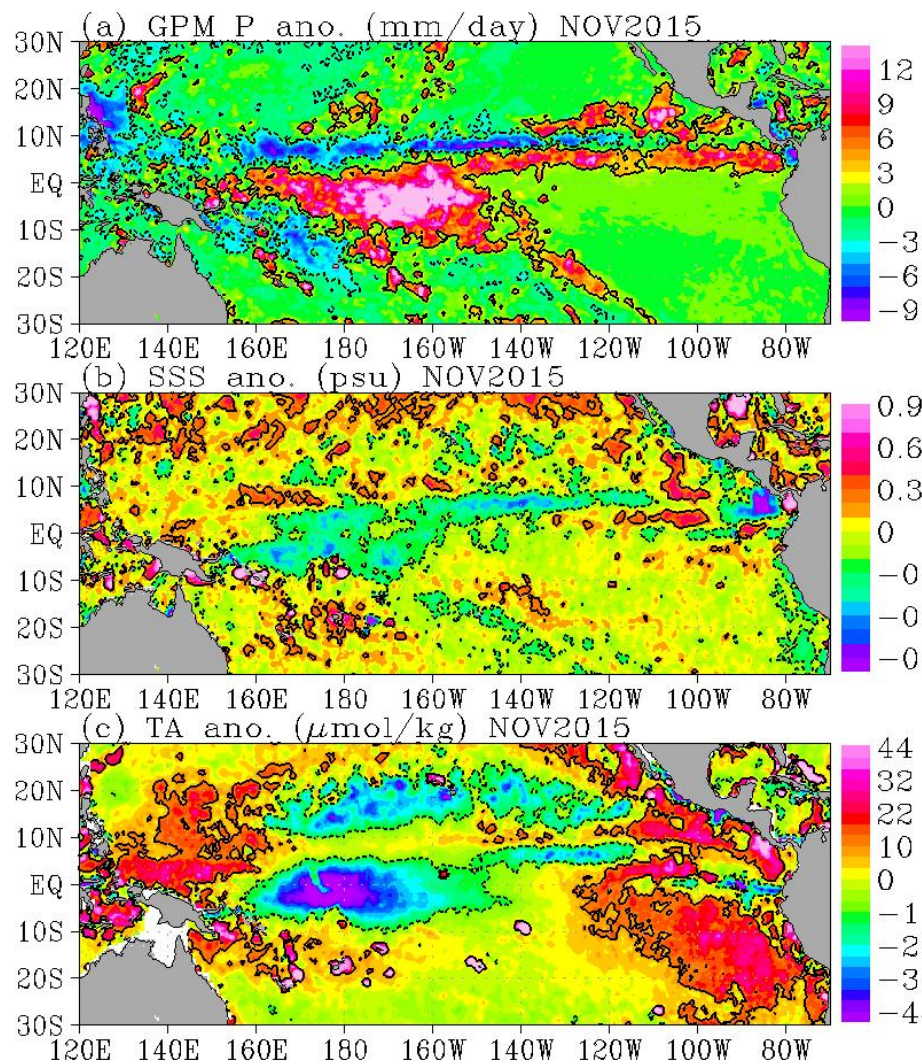


## Tropical Instability Wave

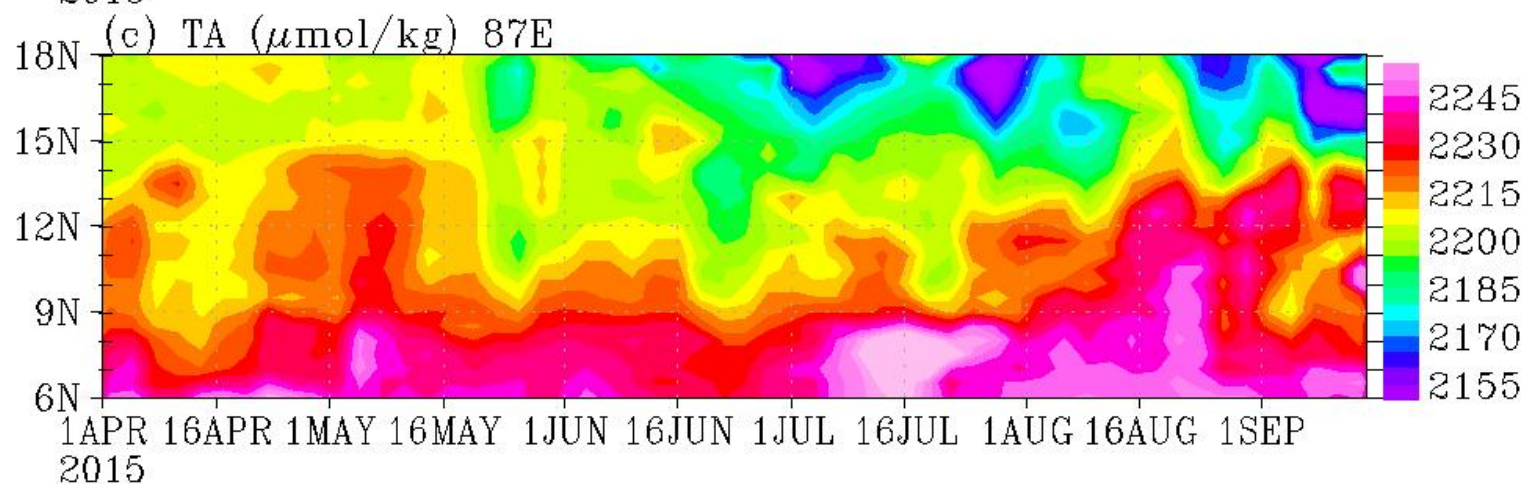
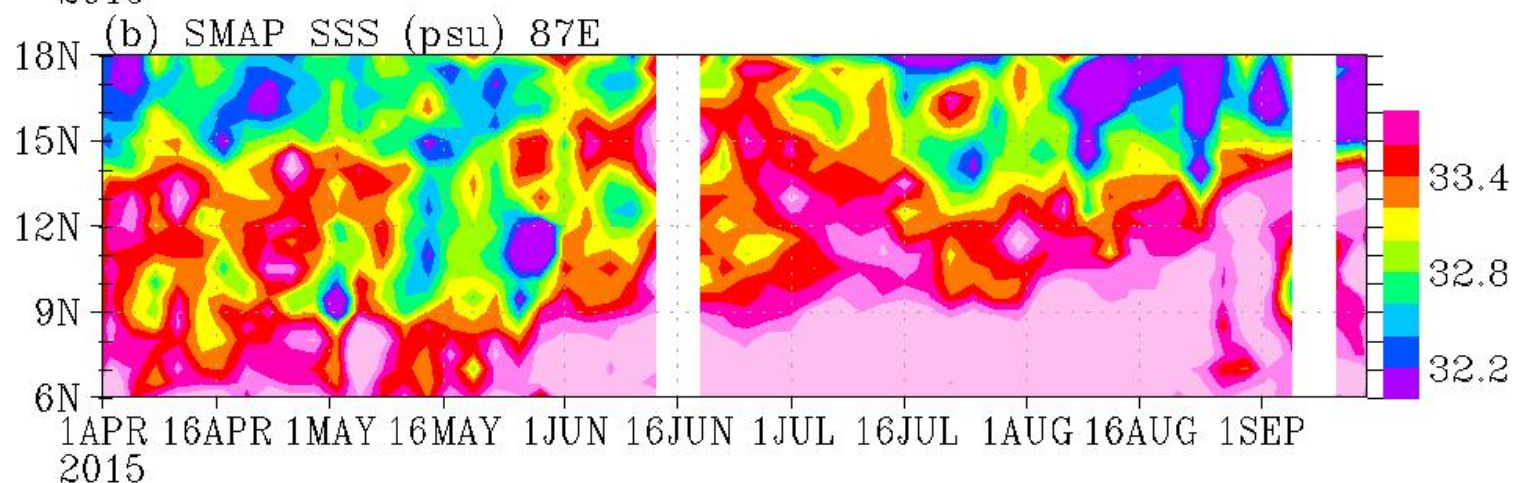
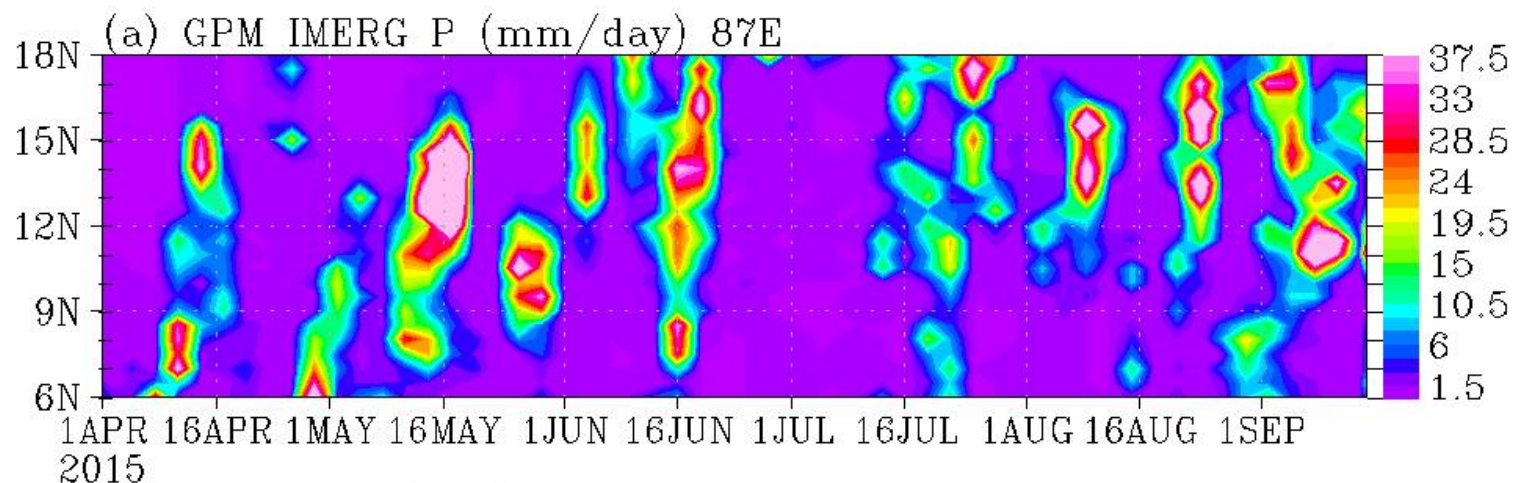




La Nina

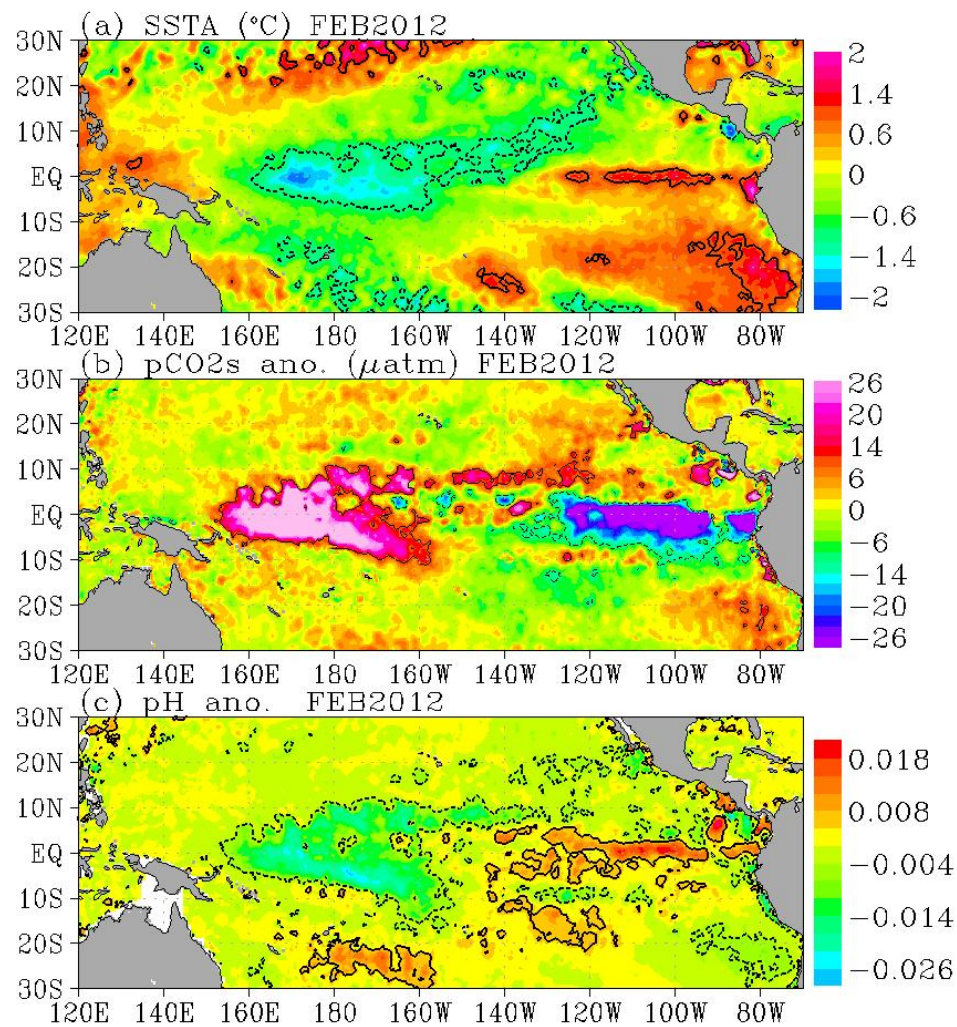
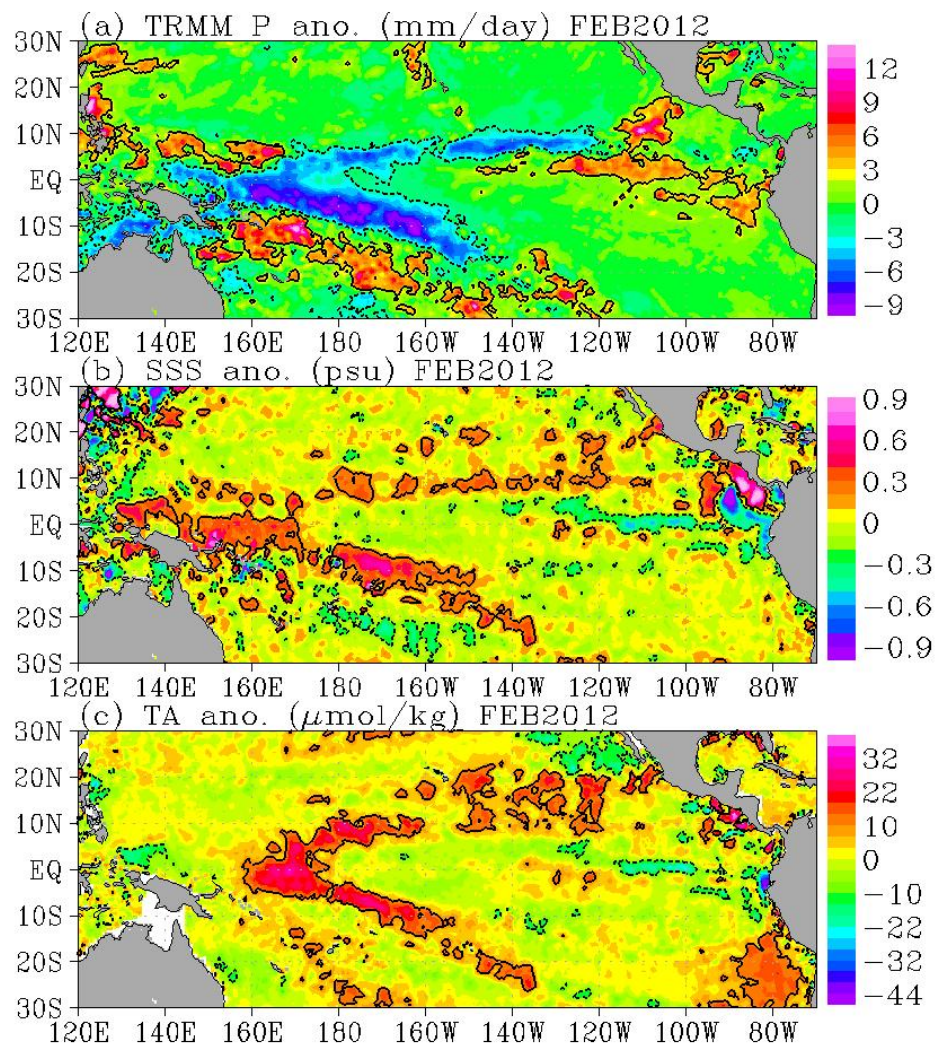


El Nino

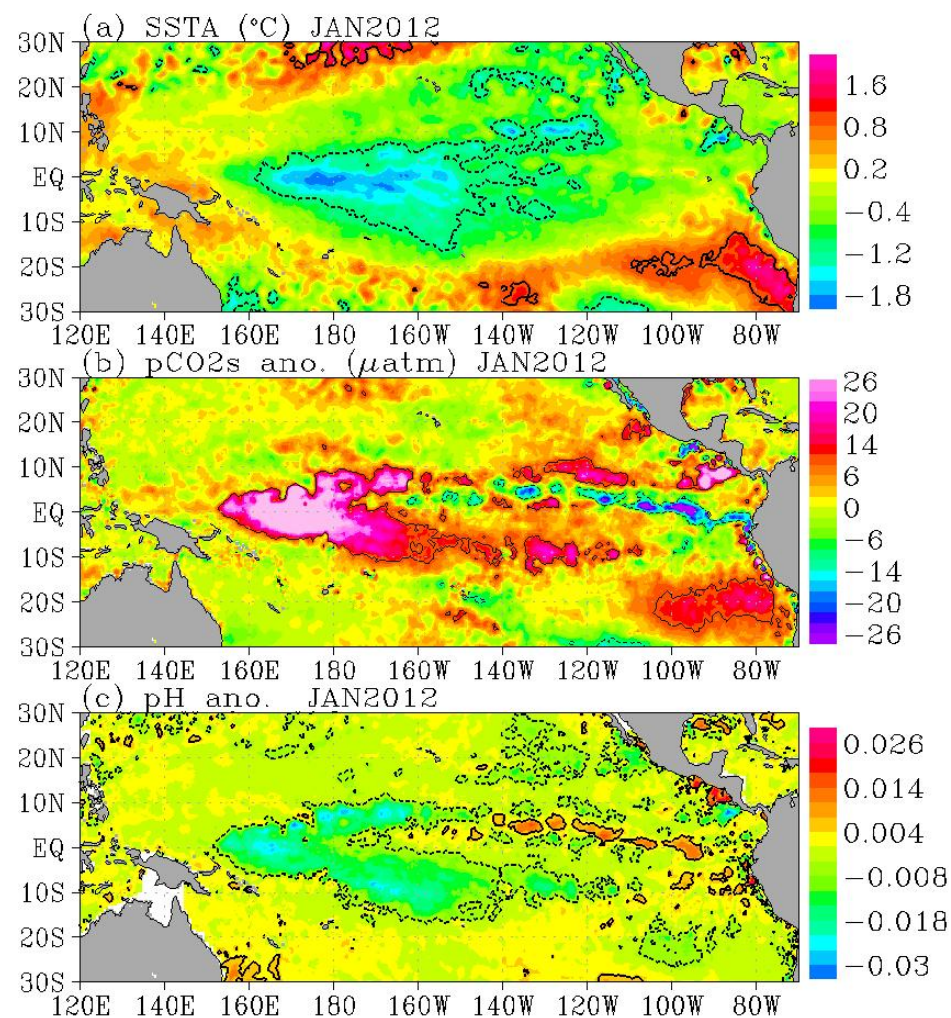
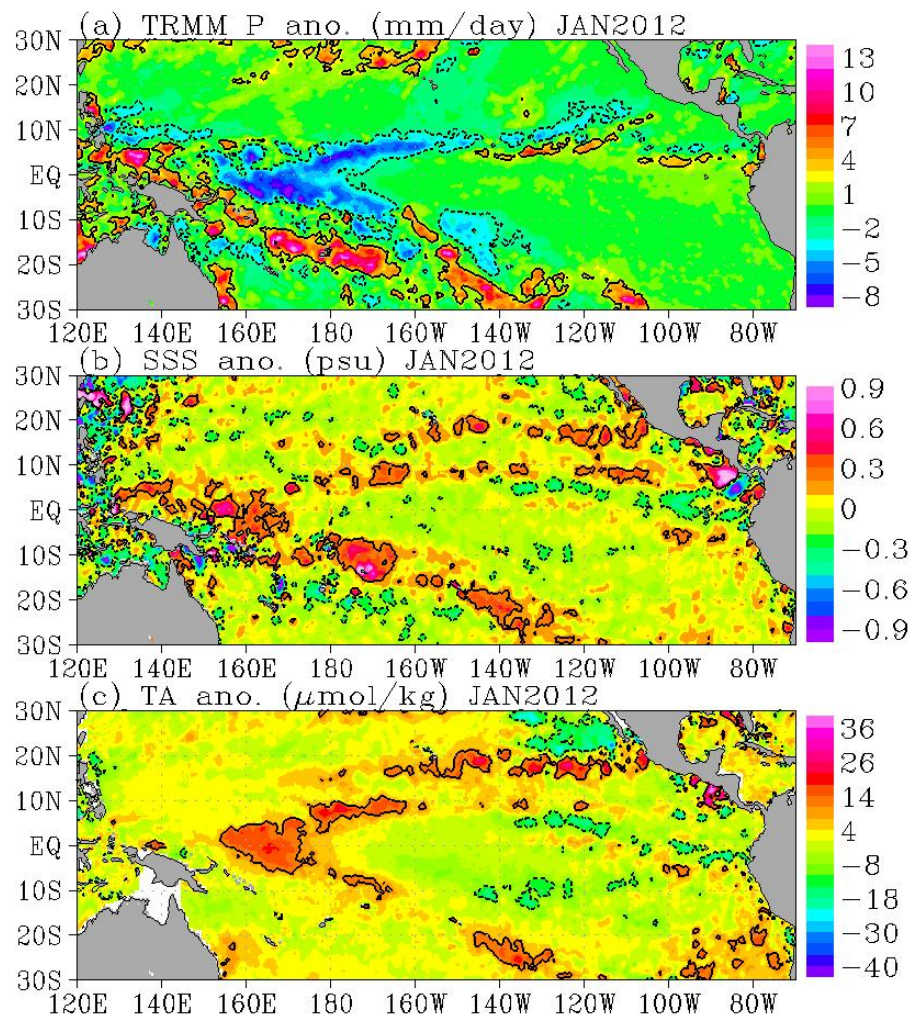


- Our outputs of carbon parameters over global ocean will reveal the temporal-spatial variability, from intraseasonal to interannual, that is not available now from in situ measurements,
- We are just starting to explore the chemical and ecological aspects of hydrological forcing.
- It will show another aspect of PMM impacts in the characterization of ocean as the source and sink of accumulated greenhouse gases in the atmosphere and the health of marine life and ecology in the ocean.

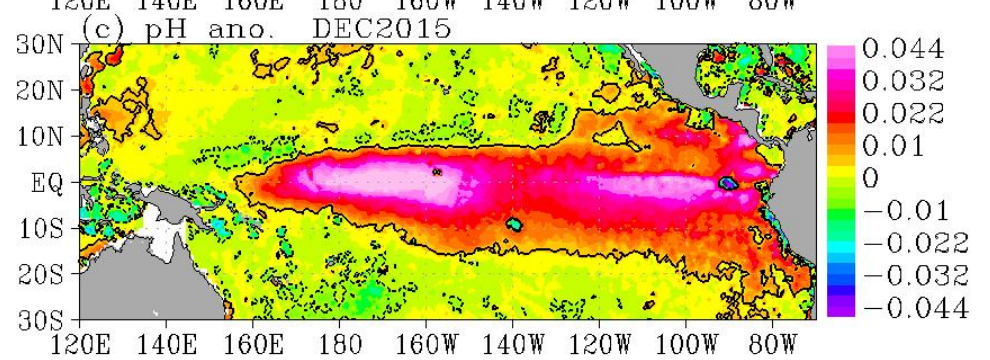
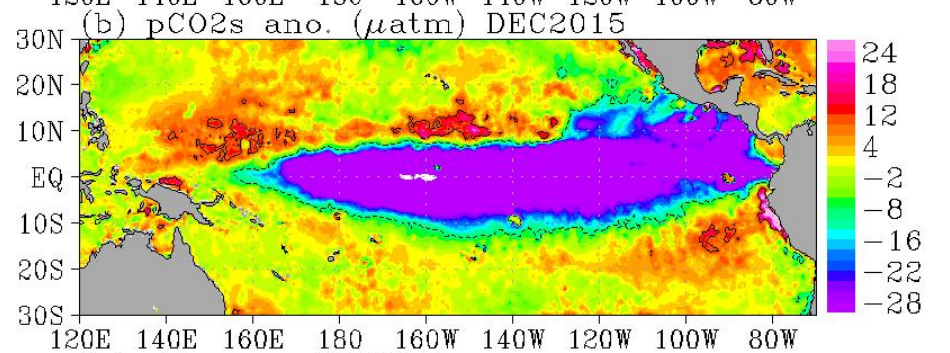
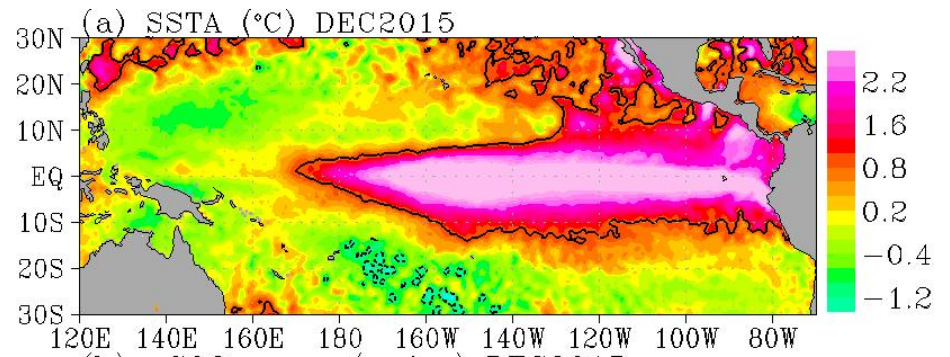
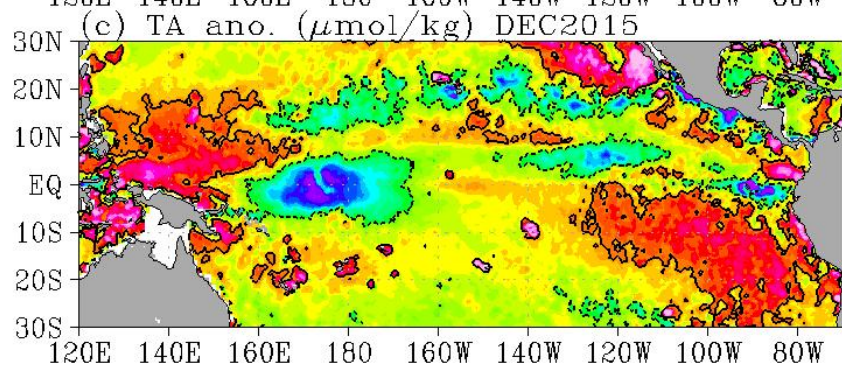
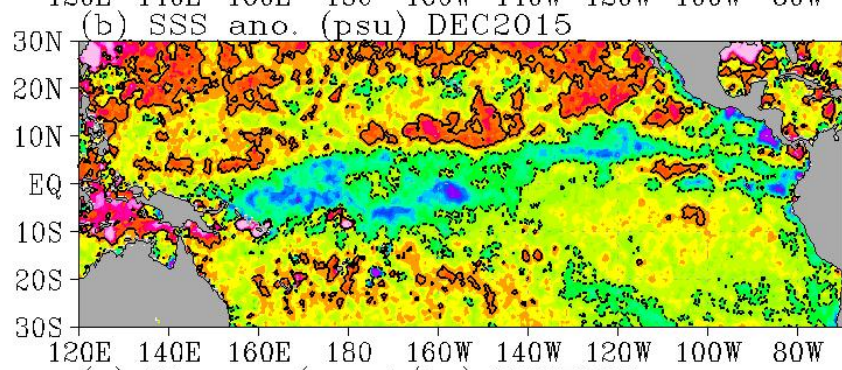
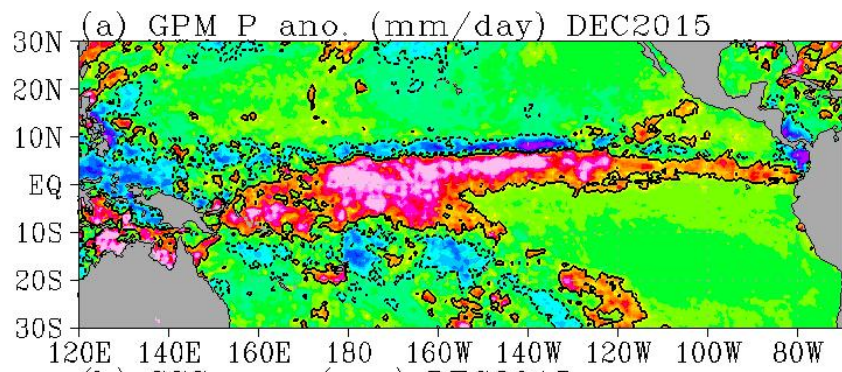
backup



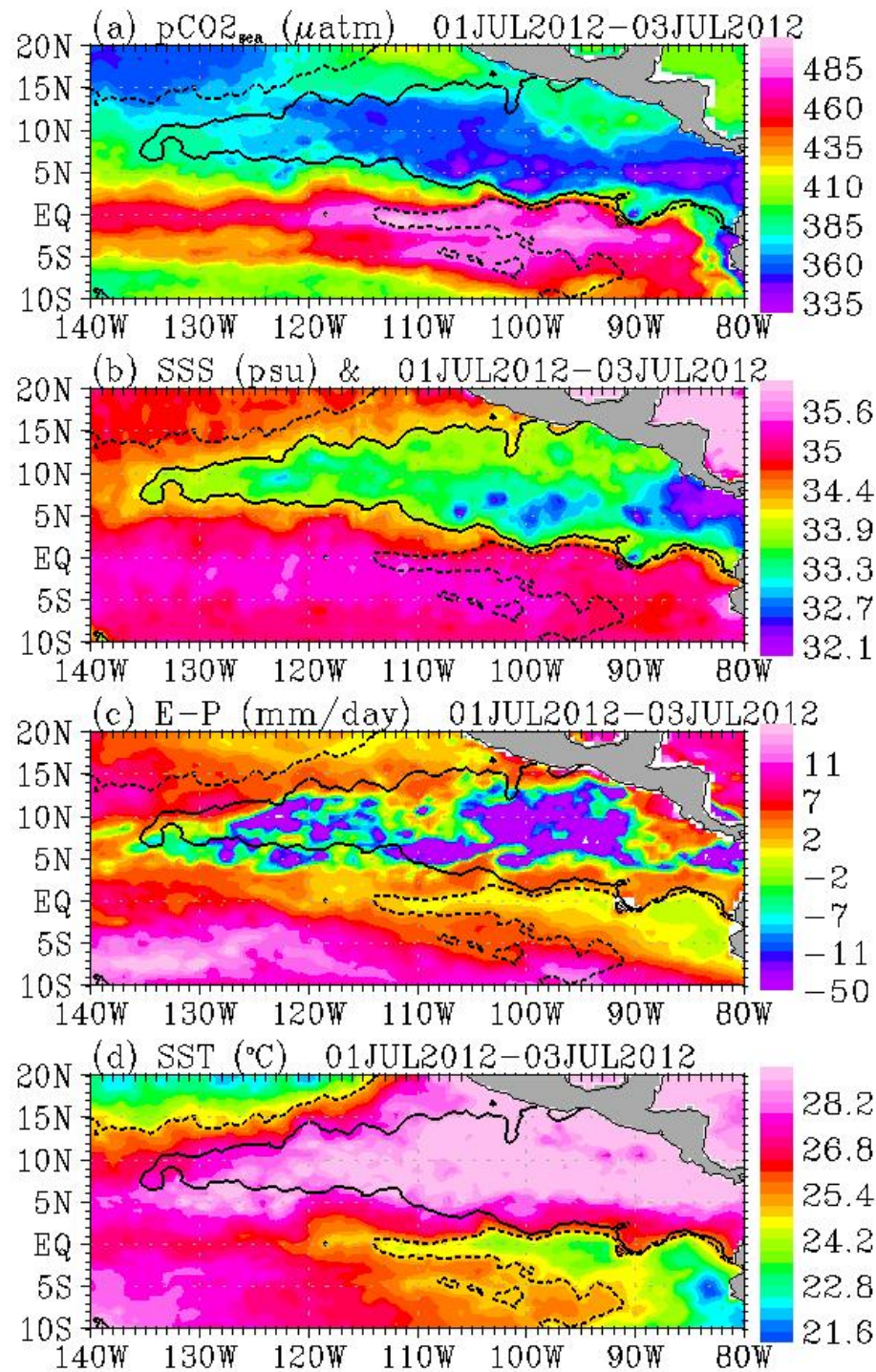
La Nina



La Nina

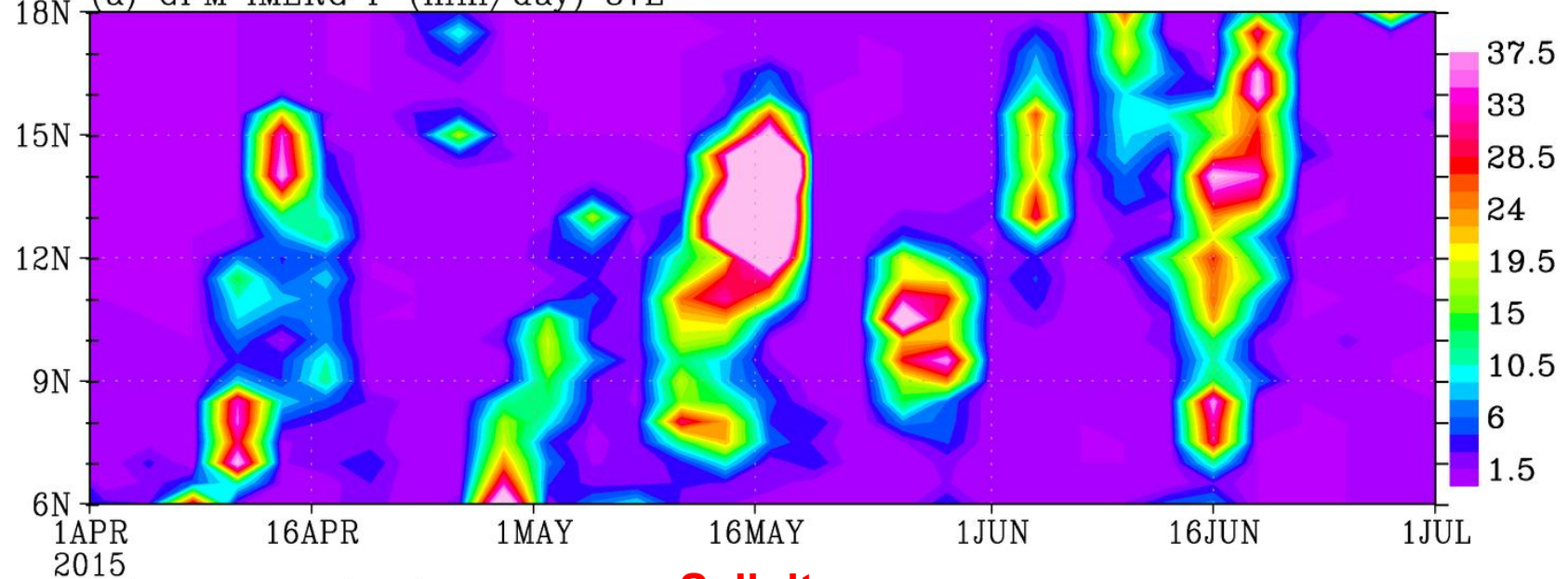


El Nino



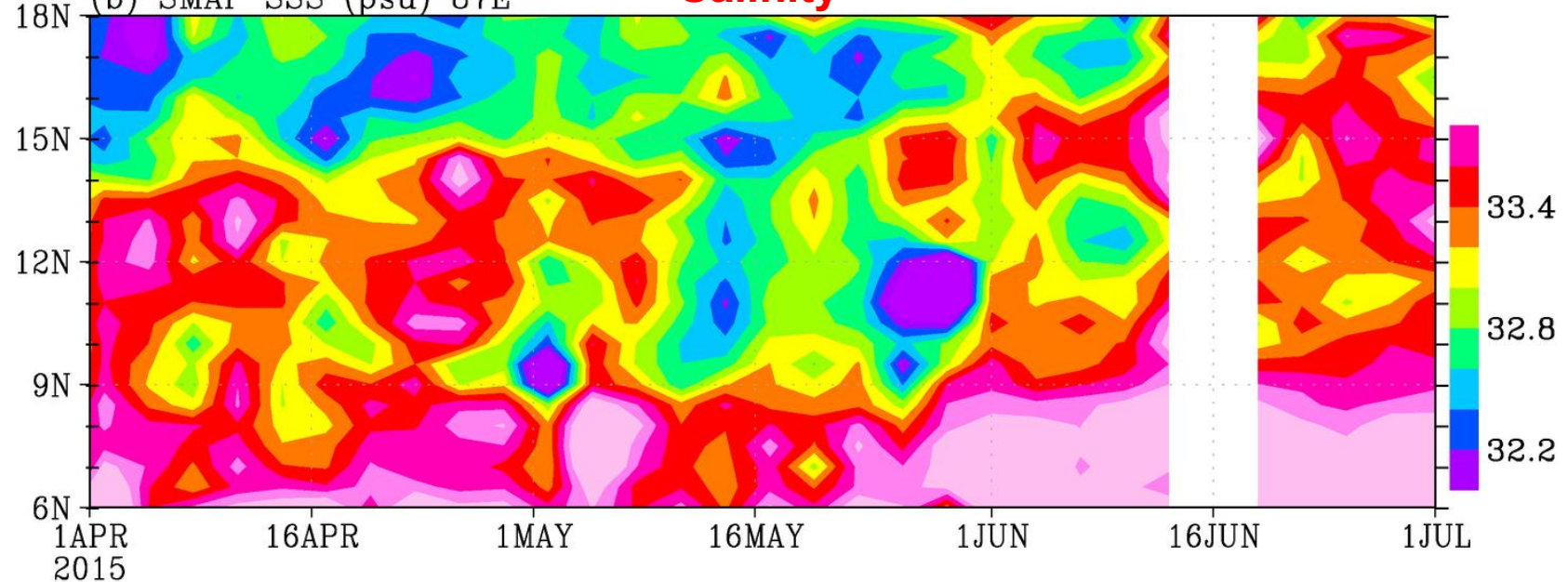
## Rain, Bay of Bengal

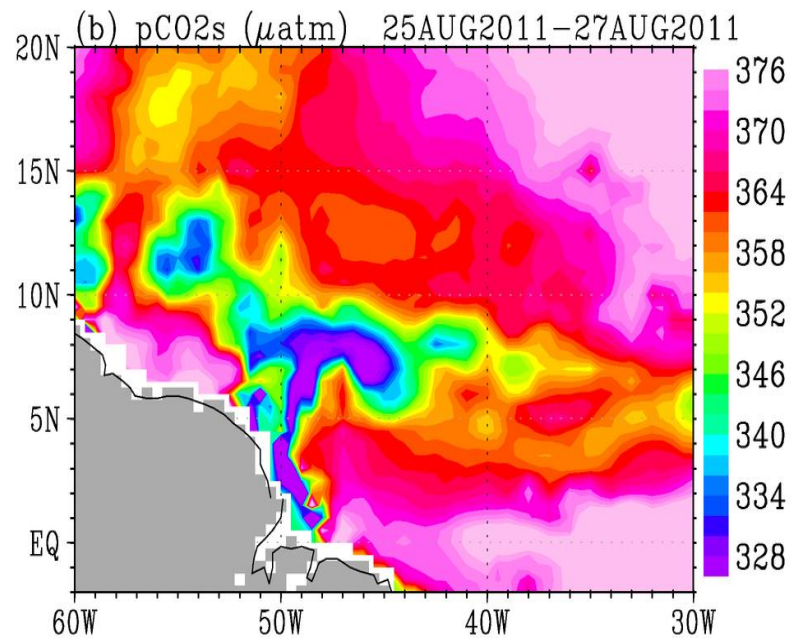
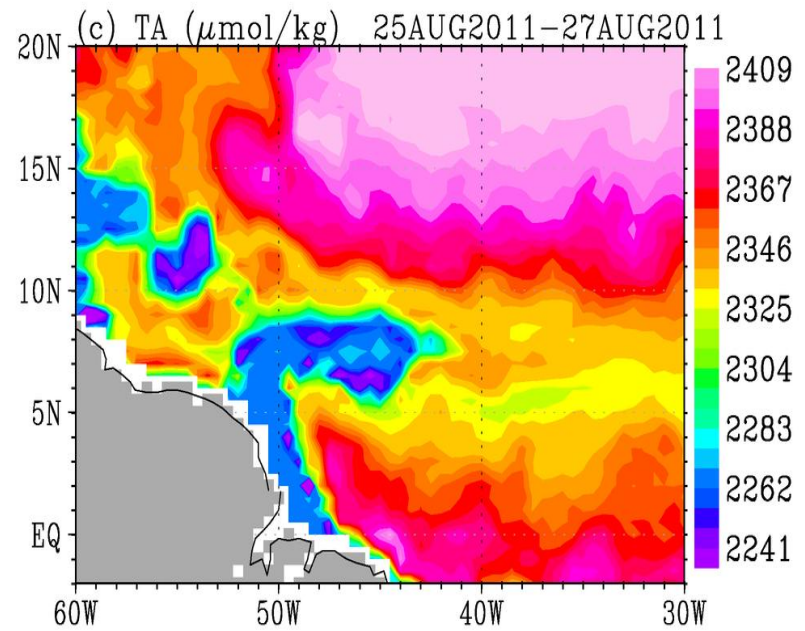
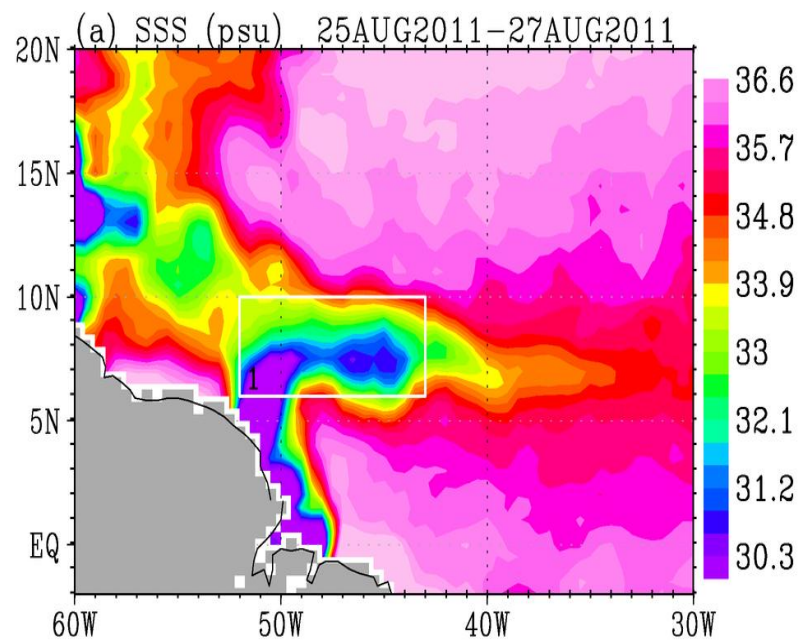
(a) GPM IMERG P (mm/day) 87E



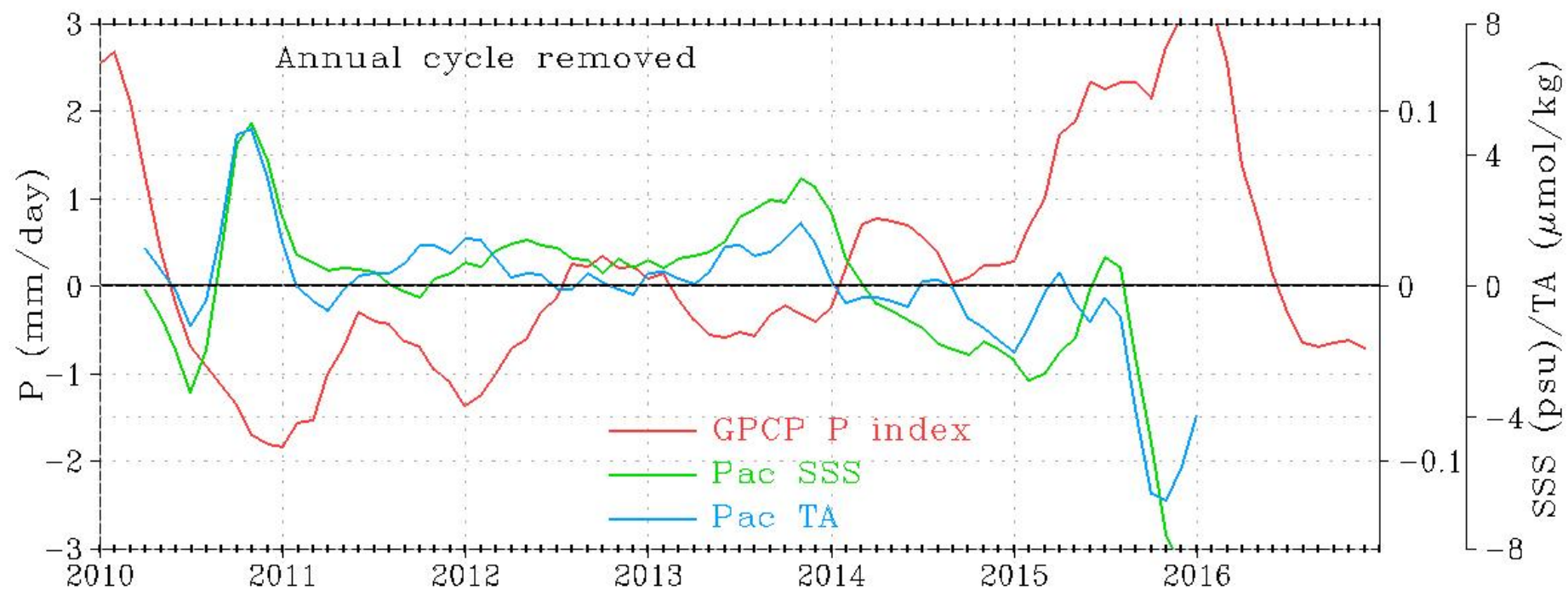
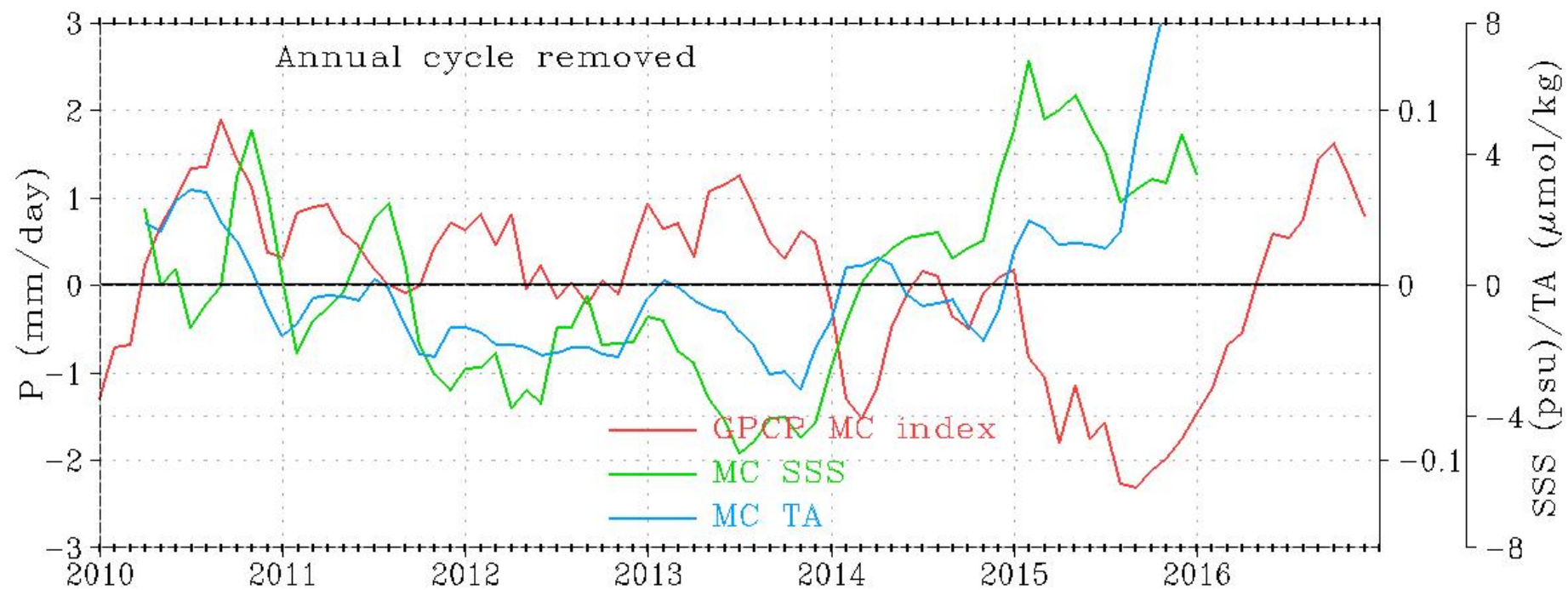
## Salinity

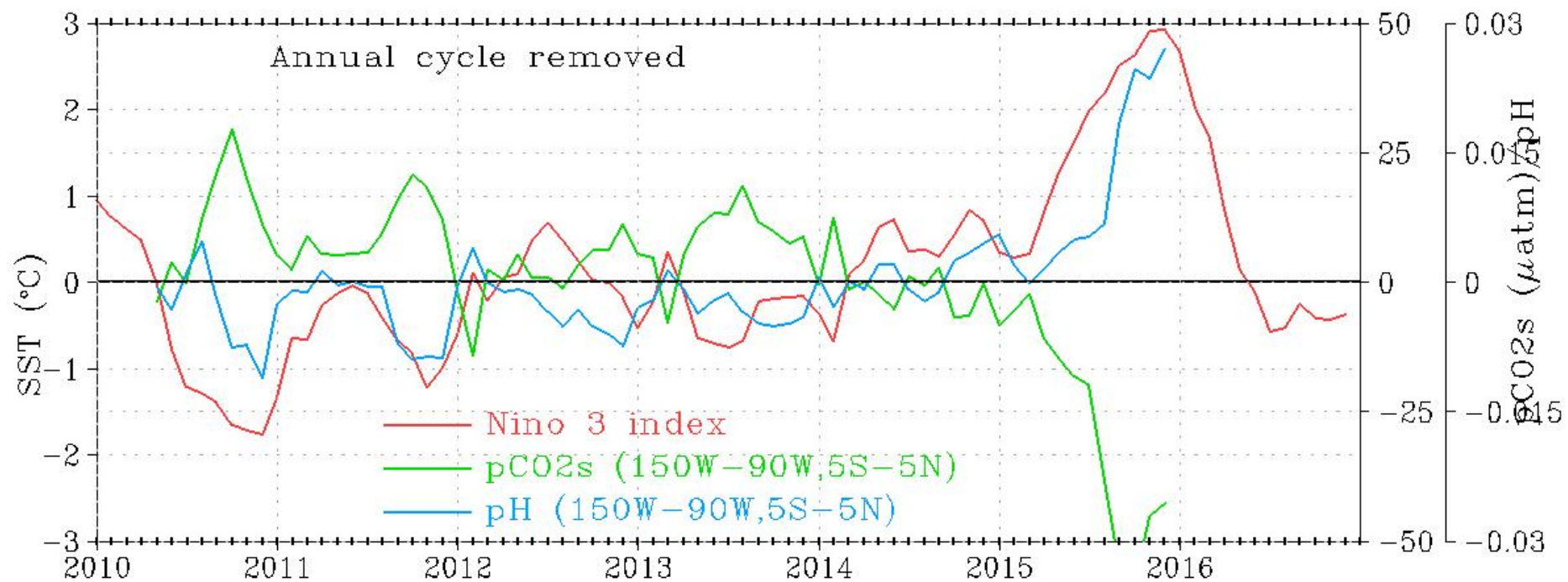
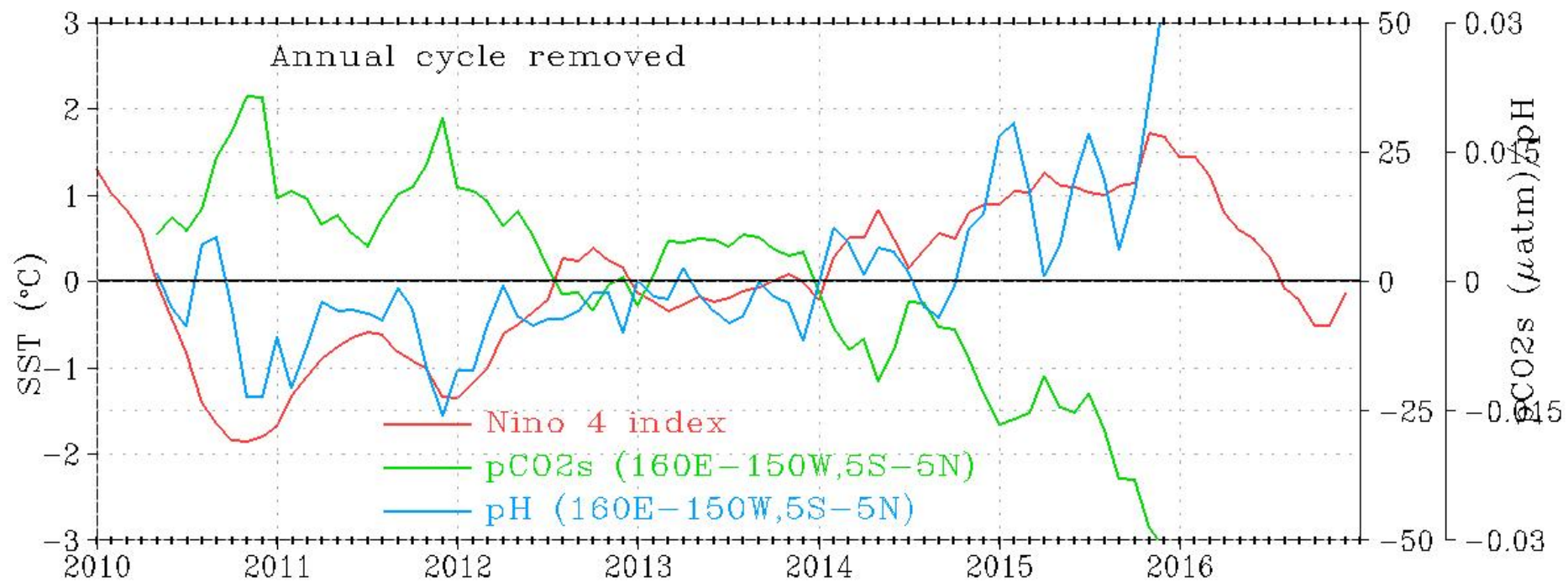
(b) SMAP SSS (psu) 87E

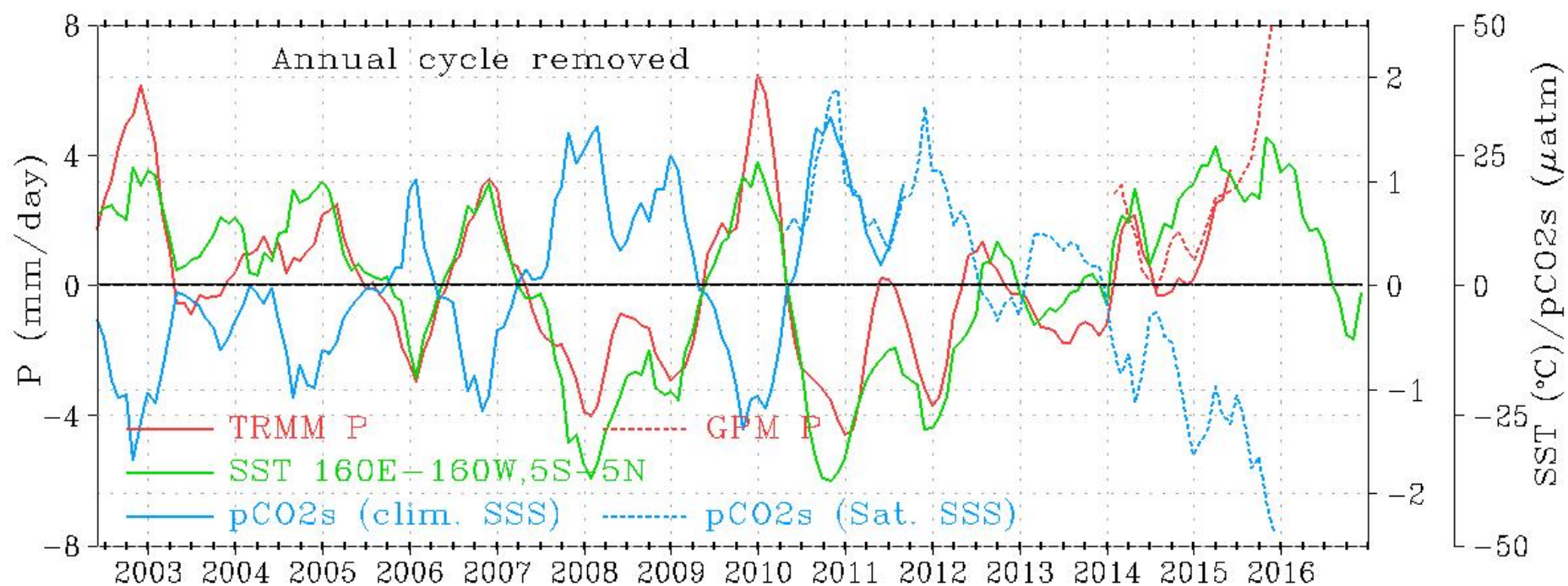
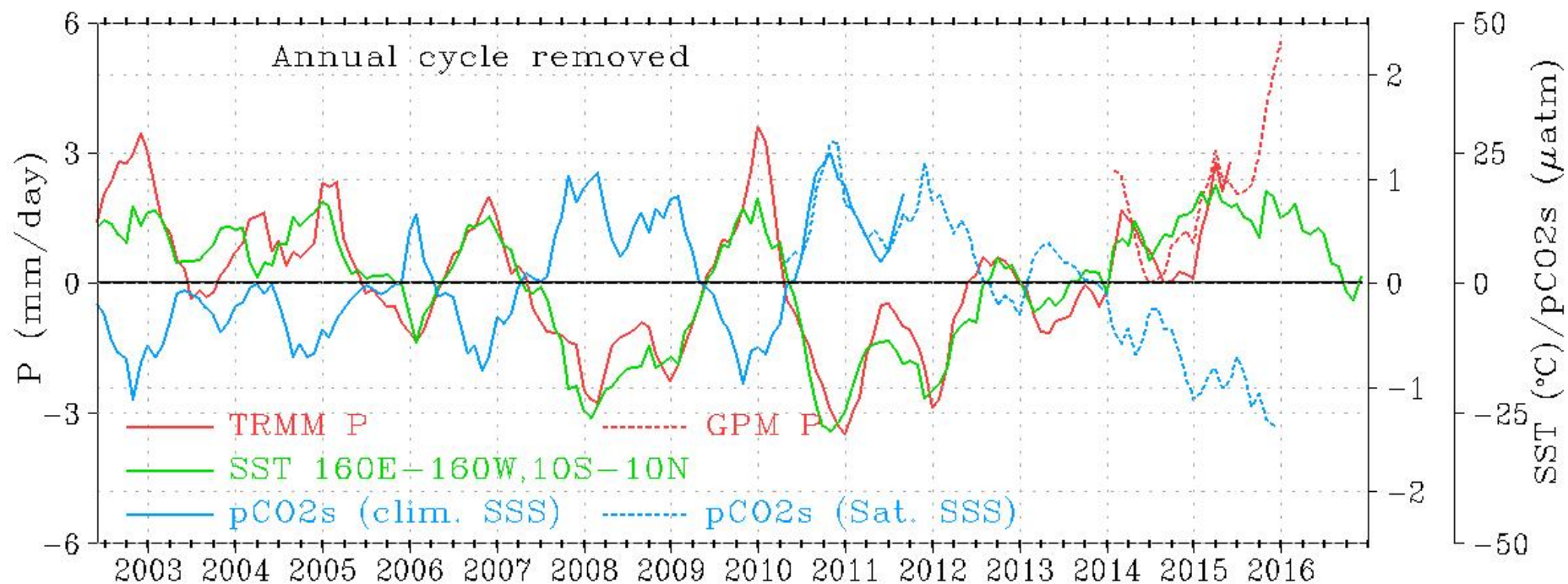


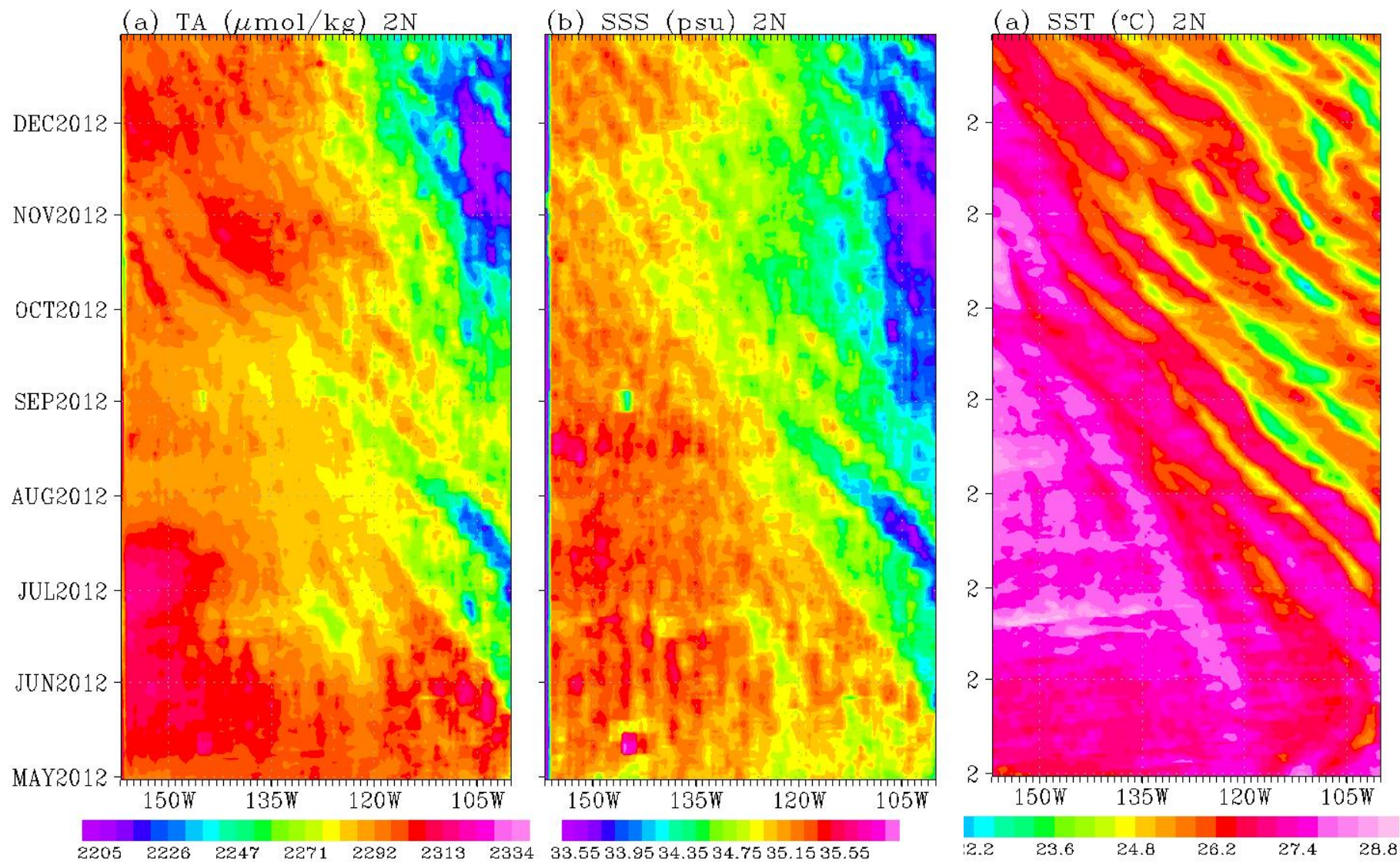


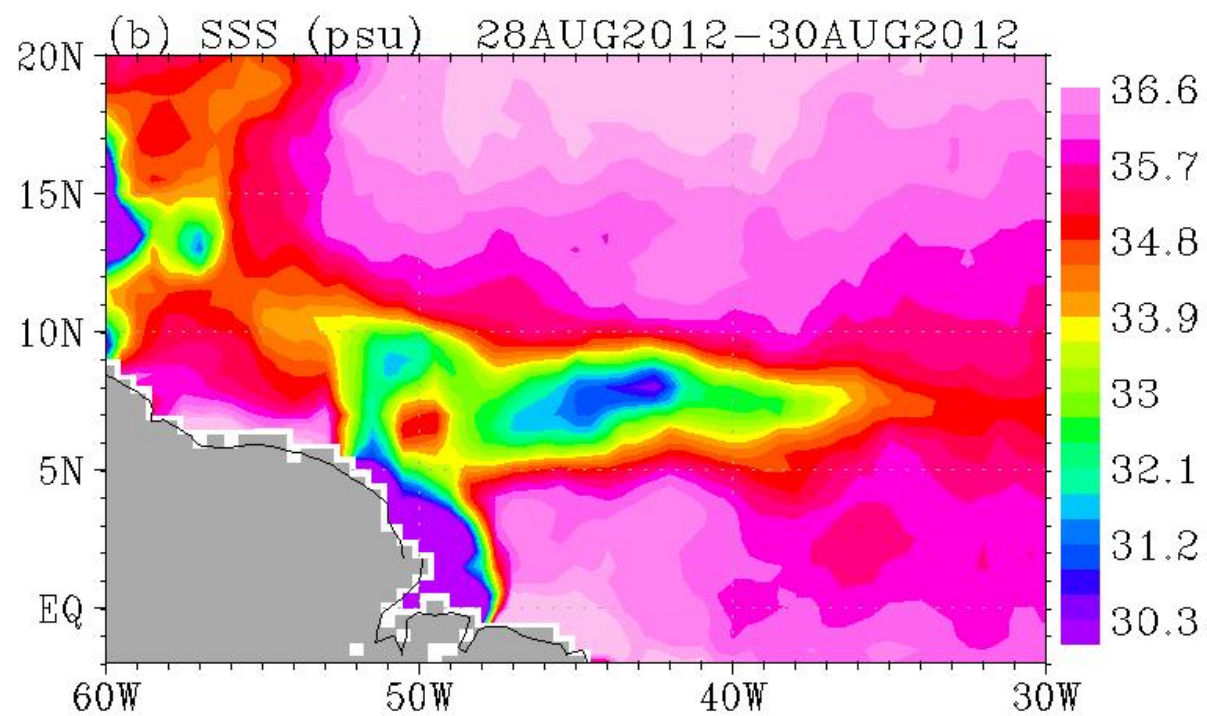
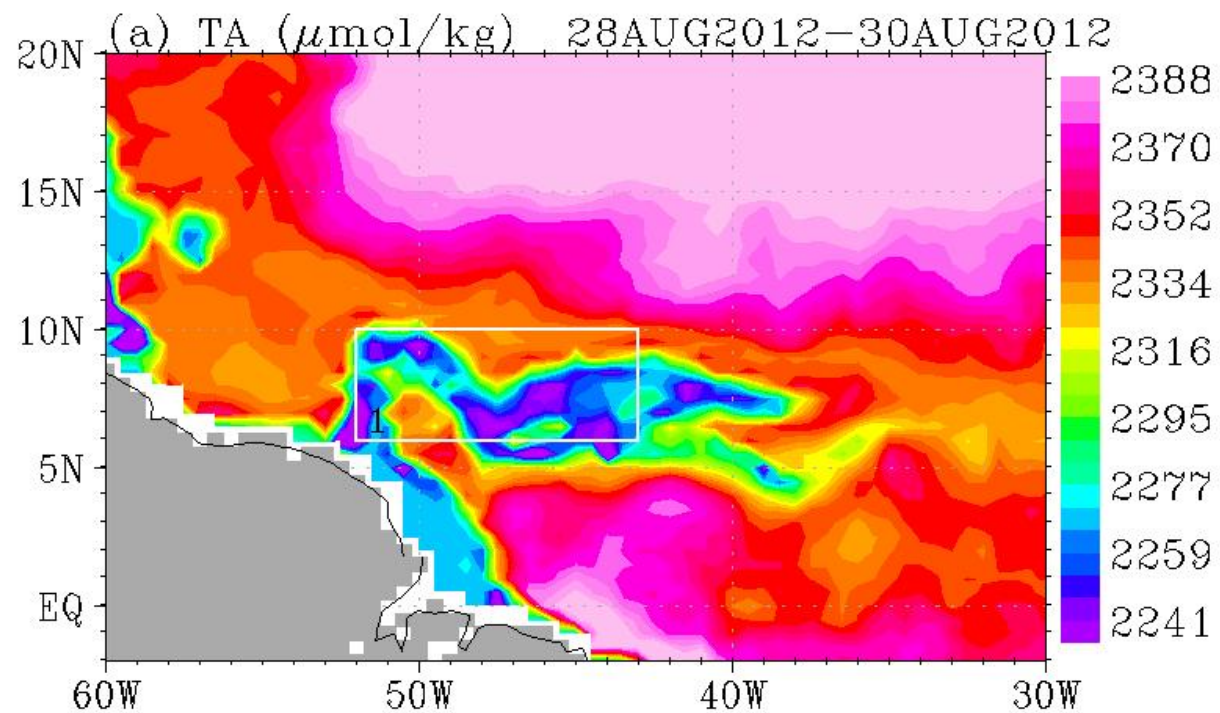
**Amazon River Plume**











- Continuous coverage of pCO<sub>2</sub> and TA over all oceans from a few days to a few years, using satellite data and a single model, is feasible.
- Ensemble validations show good accuracy, but only meaningful in regions with data.
- We found slightly less range in seasonal variation and no consistent long term trend in the tropical oceans
- Future improvement with data from SOCAT, salinity data from SMOS, Aquarius, SMAP, SST from AMSR-2, wind vector from ASCAT
- Should be complementary with OCO to determine surface source and sink of atmospheric CO<sub>2</sub>

Backup

Backup

Relation between  $p\text{CO}_{2\text{sea}}$  and other co-incident data on cruises were developed  
**SST alone**

Stephen et al. (1995)-9 cruises in Pacific in 6 years

Goyet et al. (1998) Arabian Sea

Hood et al. (1999) Greenland Sea

Nelson et al. (2001) Sargasso Sea

Cosca et al. (2001) Equatorial Pacific

**With additional Chl-a**

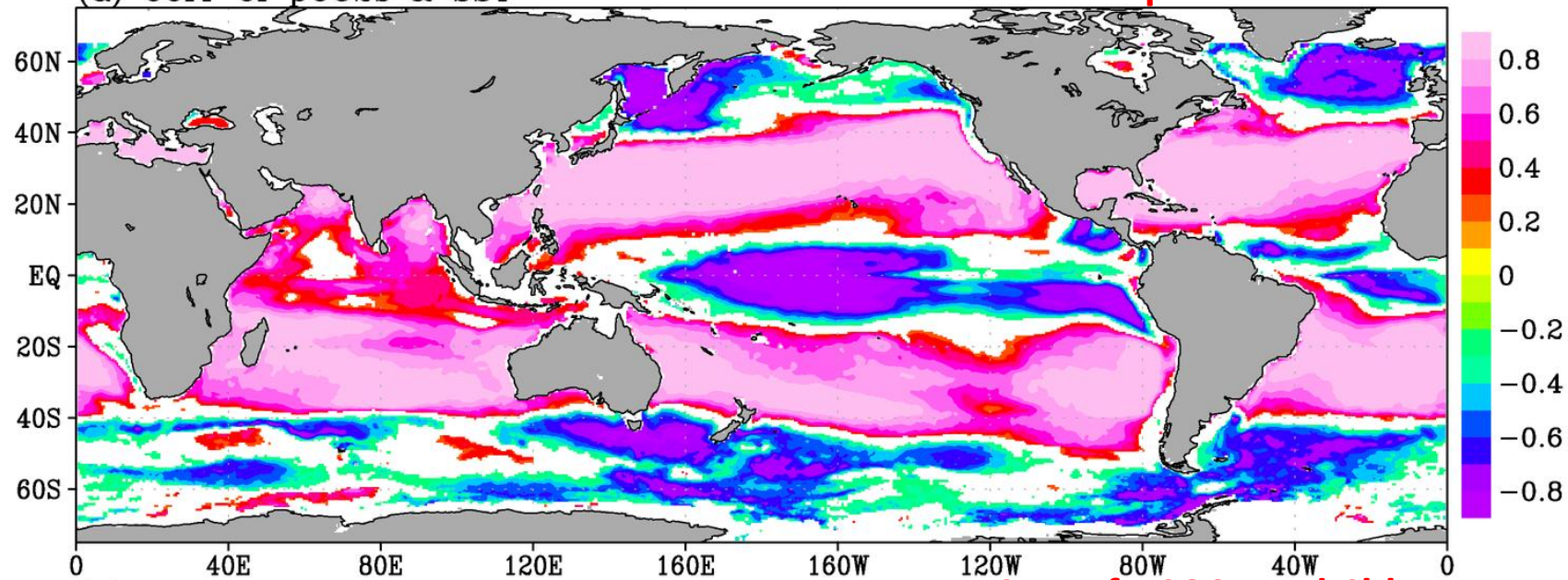
Zhu et al. (2009) South China Sea

Padin et al. (2009) Biscay Bay

**The drivers are only seasonally and regionally significant.**

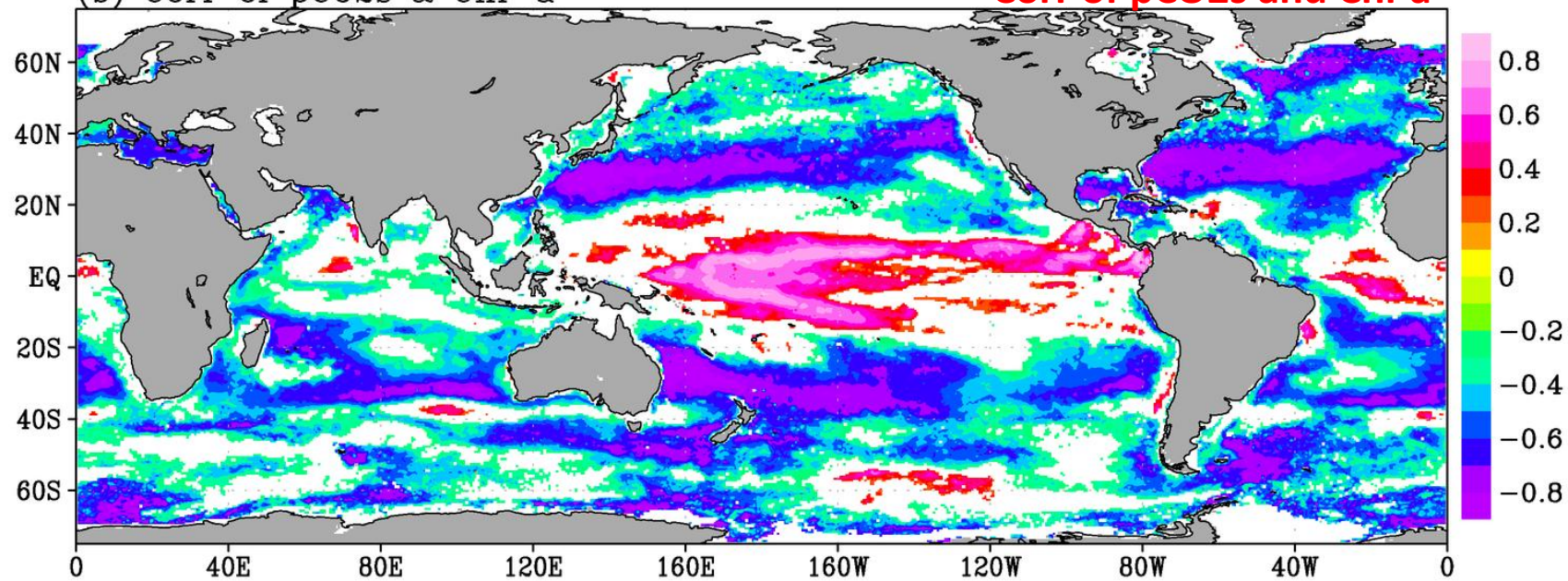
(a) Corr of pCO<sub>2</sub>s & SST

Corr of pCO<sub>2</sub>s and SST

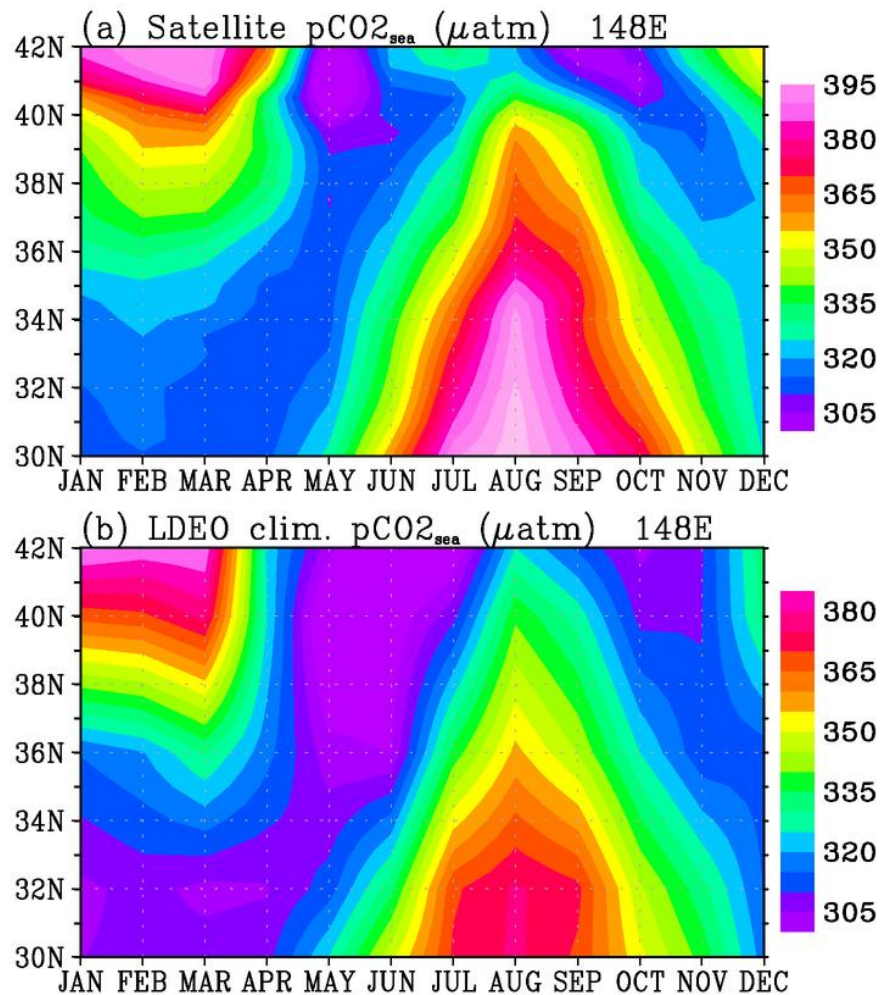


(b) Corr of pCO<sub>2</sub>s & Chl-a

Corr of pCO<sub>2</sub>s and Chl-a

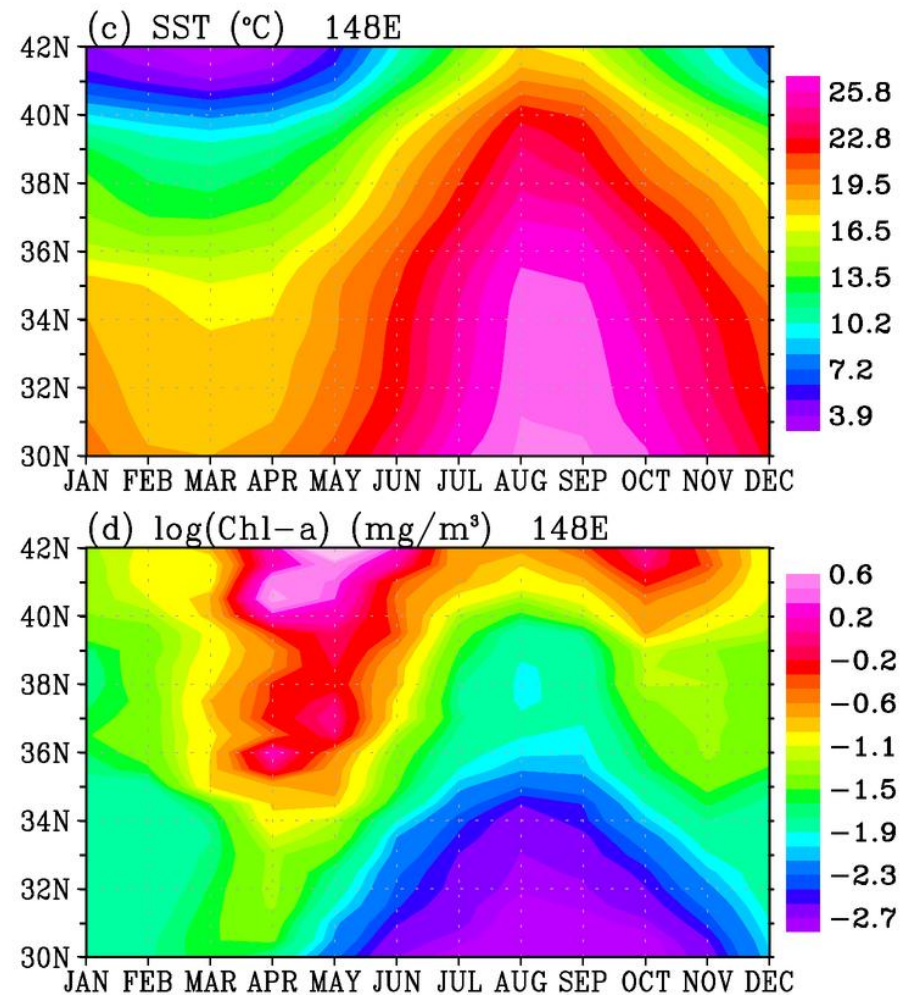


## Satellite $p\text{CO}_{2\text{sea}}$



## Takahashi $p\text{CO}_{2\text{sea}}$ clim.

## SST

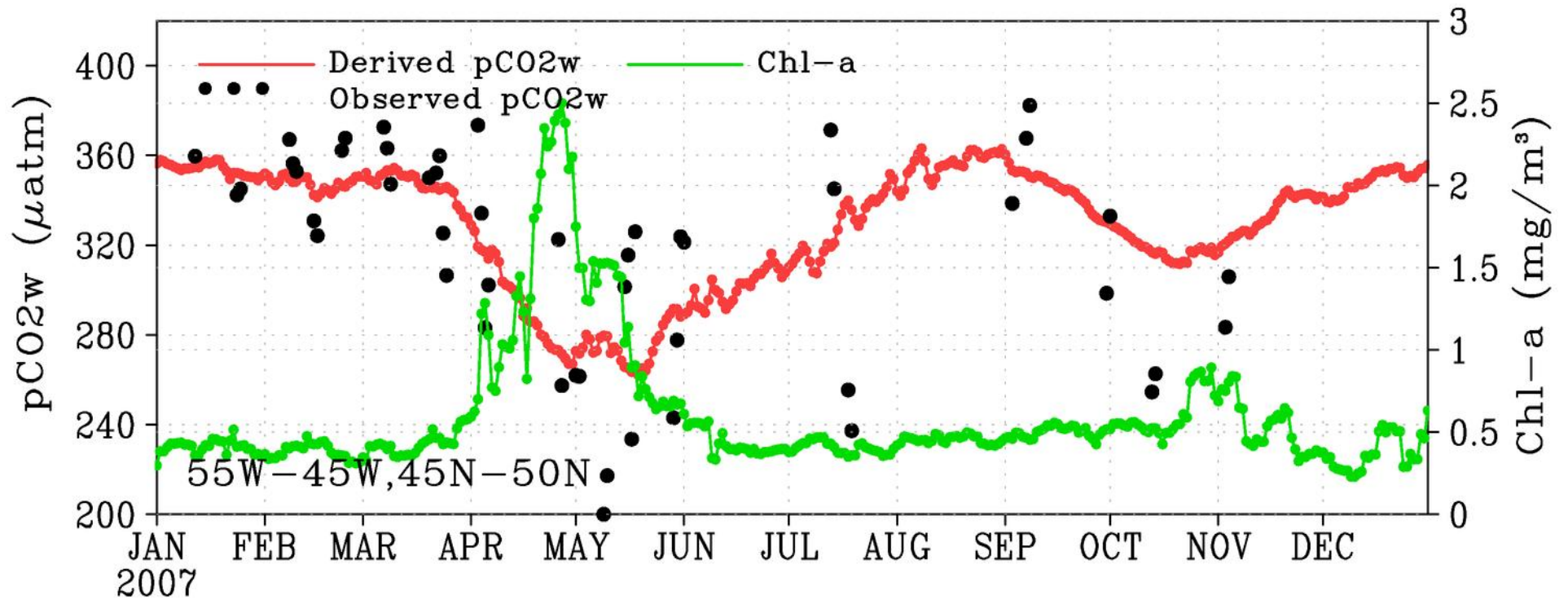


## $\log(\text{Chl-a})$

South of  $34^{\circ}\text{N}$ ,  $p\text{CO}_2$  is high in Aug-Sep and low in FEB-Mar. SST is in phase, and Chl-a is out of phase with  $p\text{CO}_2$

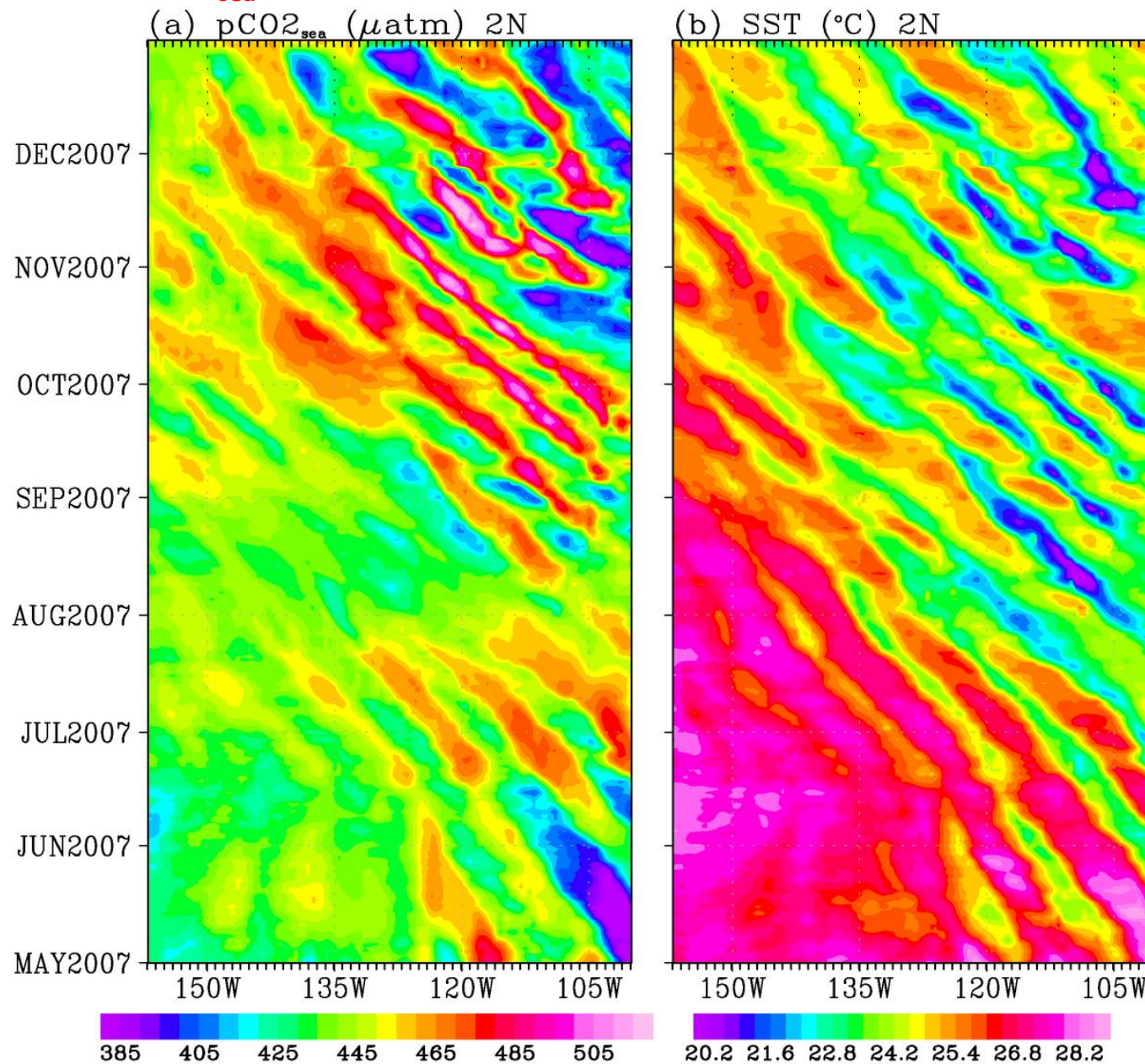
To the north,  $p\text{CO}_2$  has two peaks, in Feb and Aug, that coincide with low Chl-a. SST has only one peak

Spring bloom in North Atlantic end of April with high Chl-a and suppressed  $p\text{CO}_{2\text{sea}}$



Satellite  $p\text{CO}_{2\text{sea}}$   
Observed  $p\text{CO}_{2\text{sea}}$   
Chl-a

**Tropical Instability waves in the equatorial eastern Pacific**  
**pCO<sub>2,sea</sub> out of phase with SST**



- Ocean carbon system and acidification are usually described by 4 parameters,  $p\text{CO}_2$ , TA, dissolved inorganic carbon, and pH. Knowing two can resolve all through chemical equations. We started retrieving  $p\text{CO}_2$ , and then TA.
- $\text{CO}_2$  flux has been parameterized to a piston velocity and  $\Delta p\text{CO}_2$ .  $p\text{CO}_2$  is critical in evaluating the accumulation atmospheric greenhouse gas. Long time series has climate significance, but is difficult to compile using spacebased data.
- $p\text{CO}_2$  is important factors of governing acidification and its deleterious effect to marine ecosystems. Space data provide the spatial-temporal resolutions from intraseasonal to interannual scales and global coverage.

## Mean and standard deviation of satellite pCO<sub>2</sub>s for 2007

